PB80-215734

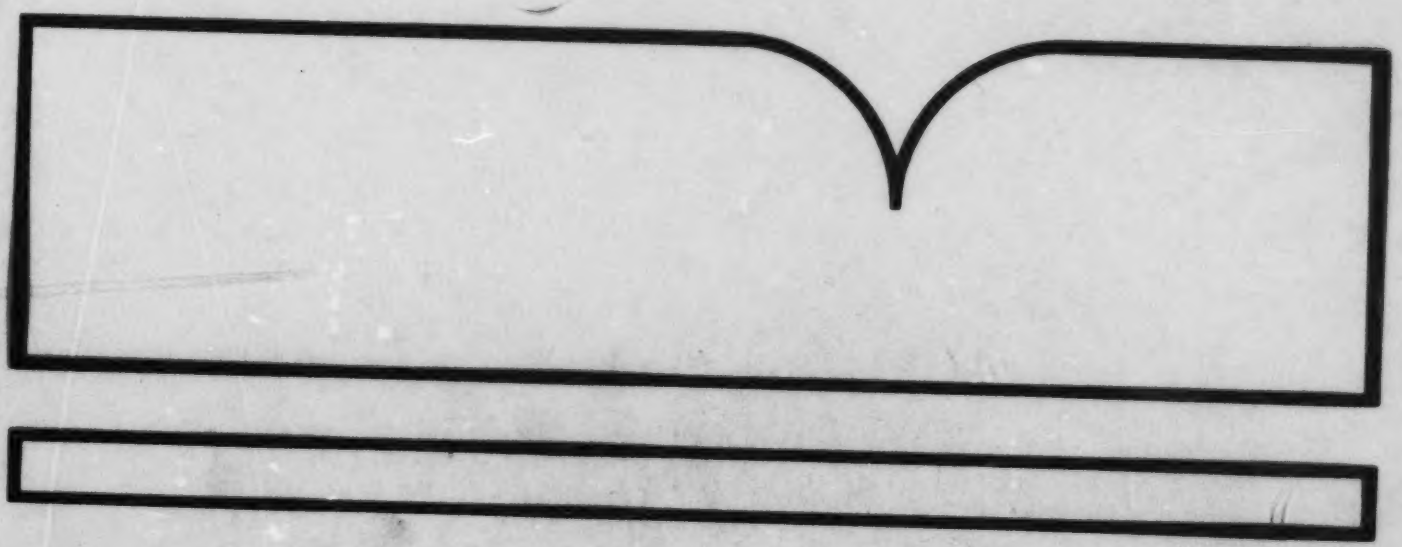
# Preliminary Environmental Assessment of Afterburner Combustion Systems

Battelle Columbus Labs., OH

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Jun 80



U.S. Department of Commerce
National Technical Information Service
NTIS.

**TECHNICAL REPORT DATA**
*(Please read Instructions on the reverse before completing)*

| 1. REPORT NO. | 2. | 3. RECIPIENT'S ACCESSION NO. |
|---|---|---|
| | IERL-RTP-1081 | PB 80 215734 |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| Preliminary Environmental Assessment of Afterburner Combustion Systems | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
| Richard E. Barrett and Phillip R. Sticksel | |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. PROGRAM ELEMENT NO. |
| Battelle Columbus Laboratories<br>505 King Avenue<br>Columbus, Ohio 43201 | INE829 |
| | 11. CONTRACT/GRANT NO. |
| | 68-02-2629 |
| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT AND PERIOD COVERED |
| EPA, Office of Research and Development<br>Industrial Environmental Research Laboratory<br>Research Triangle Park, NC 27711 | Final; 3/77-6/80 |
| | 14. SPONSORING AGENCY CODE |
| | EPA/600/13 |

15. SUPPLEMENTARY NOTES IERL-RTP project officer is John H. Wasser, Mail Drop 65, 919/541-2476.

16. ABSTRACT The report gives results of an environmental assessment of afterburner control systems (fume incinerators). It consisted of a review of available data and literature, and the planning of a subsequent experimental program, intended to consist of laboratory and/or field emission measurements to provide data not presently available. The report describes the use of existing data to estimate the potential national usage of afterburners based on emissions. It also reports on an evaluation of field test data from the files of one local air pollution control agency. Results of the analyses show that the average efficiency of in-service afterburners may be significantly less than that reported in much of the literature. Although a lower afterburner efficiency is likely to have little impact on national organic nonmethane emissions, it may have marked impact in local areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group | |
|---|---|---|---|---|
| Pollution | Hydrocarbons | Pollution Control | 13B | 07C |
| Assessments | Organic Compounds | Stationary Sources | 14B | |
| Afterburners | Dust | Environmental Assessment | 21J | 11G |
| Fumes | | | | |
| Combustion | | Emission Regulations | 21B | |
| Incinerators | | Particulate | | |

| 18. DISTRIBUTION STATEMENT | 19. SECURITY CLASS *(This Report)* | 21. NO. OF PAGES |
|---|---|---|
| Release to Public | Unclassified | 125 |
| | 20. SECURITY CLASS *(This page)* | 22. PRICE |
| | Unclassified | |

EPA Form 2220-1 (9-73)

PB80-215734

EPA-600/7-80-153
June 1980

# Preliminary Environmental Assessment of Afterburner Combustion Systems

by

Richard E. Barrett
and
Phillip R. Sticksel

Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Contract No. 68-02-2629
Program Element No. INE829

EPA Project Officer: John H. Wasser

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

## ABSTRACT

The objective of this program was to conduct an environmental assessment of afterburner control systems (fume incinerators). Phase I consisted of a review of available data and literature, and the planning of a subsequent experimental program. Phase II is intended to consist of laboratory and/or field emission measurements to provide data not presently available.

This report describes the Phase I environmental assessment conducted on the program. Firstly, it reports on the use of existing data to estimate the potential national usage of afterburners based on emissions. Secondly, it reports on an evaluation of field test data from the files of one local air pollution control agency. Results of the analyses show that the average efficiency of in-service afterburners may be significantly less than that reported on in much of the literature. A lower afterburner efficiency is likely to have little impact on national organic nonmethane emissions, but may have marked impact in local areas.

TABLE OF CONTENTS


| | Page |
|---|---|
| ABSTRACT | ii |
| ACKNOWLEDGMENT | vi |
| INTRODUCTION | 1 |
| SUMMARY | 3 |
| REVIEW OF AIR POLLUTION REGULATIONS FOR CONTROLLING HYDROCARBONS FROM STATIONARY POINT SOURCES | 4 |
| Ambient Standards for Hydrocarbons | 5 |
| Emission Standards for Hydrocarbon Sources | 5 |
| Los Angeles Regulations | 6 |
| Emission Standards for Equipment Discharging Organic Solvents to the Atmosphere | 6 |
| Hydrocarbon Emission Standards for Specified Sources | 10 |
| Comments on 1300 F, 0.3 Second Residence Time as Basis for Organic Emission Regulations | 12 |
| Standards for Storage and Transfer of Petroleum Products | 17 |
| HYDROCARBON POLLUTANT EMISSIONS AND THEIR POTENTIAL FOR CONTROL | 18 |
| Tabulation of U. S. Hydrocarbon Emissions and Impact of Control Devices | 18 |
| U. S. Hydrocarbon Emissions and Impact of Control Devices | 25 |
| COLLECTION AND EVALUATION OF AFTERBURNER TEST RESULTS | 31 |
| Tabulation of Available Afterburner Test Results | 34 |
| Evaluation of Available Afterburner Test Results | 39 |
| Aldehydes | 44 |
| IMPACT OF LESS EFFICIENT AFTERBURNERS ON HYDROCARBON EMISSIONS | 45 |
| RECOMMENDATIONS FOR FURTHER RESEARCH | 47 |
| Field Program of Emission Measurement For In-Service Afterburners | 48 |
| Program to Relate Afterburner Performance To Major Design Variables | 49 |

TABLE OF CONTENTS
(Continued)


| | Page |
|---|---|
| Limits to Laboratory Testing of Afterburners | 49 |
| Limits to Field Testing | 50 |
| Advantages of Mobile Afterburner Test Unit | 51 |
| REFERENCES | 52 |

APPENDIX A

LOS ANGELES HYDROCARBON VAPOR REGULATIONS . . . . . A-1

APPENDIX B

AFTERBURNER QUESTIONNAIRE . . . . . B-1

APPENDIX C

RESPONSES TO AFTERBURNER QUESTIONNAIRE BY FOUR MANUFACTURERS . . . . . C-i

CONTENTS . . . . . C-ii


LIST OF TABLES


| | | |
|---|---|---|
| Table 1. | Emission Regulations Applying to General Sources of Organic Emissions | 8 |
| Table 2. | Operations Excluded from Organic Solvent Law by One or More States | 11 |
| Table 3. | State Hydrocarbon Emission Standards For Specific Point Sources | 13 |
| Table 4. | Concentration Ratio After 0.3 Sec at 1300 F, Based on Reference 10 | 16 |
| Table 5. | Principal Sources of Hydrocarbom Emissions of the Air | 21 |
| Table 6. | Summary of National Organic Emissions From Stationary Sources Amenable to Emissions Control | 22 |
| Table 7. | Summary of National Organic Emissions from Stationary Sources Amenable to Afterburner Emission Controls | 24 |
| Table 9. | Afterburner Performance Tests | 35 |

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES


| | | Page |
|---|---|---|
| Figure 1 | National Volatile Nonmethane Organic Emissions from Stationary Sources . . . . . | 26 |
| Figure 2 | National Volatile Nonmethane Organic Emissions from Stationary Sources Showing Afterburner Controllable Emissions . . . . . | 28 |
| Figure 3 | National Organic Particulate Emissions From Stationary Sources . . . . . | 29 |
| Figure 4 | National Organic Particulate Emissions From Stationary Sources Showing Afterburner Controllable Emissions . . . . . | 30 |
| Figure 5 | Afterburner Efficiency Based on Total Organics . . . . . | 40 |
| Figure 6 | Afterburner Efficiency Based on Reactive Organics . . . . . | 42 |
| Figure 7 | Comparison of Afterburner Efficiencies For Total and Reactive Organics . . . . . | 43 |

## ACKNOWLEDGMENT

We would like to acknowledge the assistance of the Industrial Gas Cleaning Institute and the IGCI Technical Director, Sidney R. Orem, for arranging for the questionnaire to be completed by several IGCI member companies. Our thanks also are extended to the unidentified companies who responded to the questionnaires.

# A PRELIMINARY ENVIRONMENTAL ASSESSMENT OF AFTERBURNER COMBUSTION SYSTEMS

Richard E. Barrett and Philip R. Sticksel

## INTRODUCTION

Organic emissions are of concern because of their participation in reactions leading to the production of oxidants and, because in certain locales, further reactions produce aerosols as well as irritating smogs. One type of device that can be utilized for the control of hydrocarbon or organic emissions from some stationary sources is the afterburner, or fume incinerator.

Afterburners can be applied to some, but not all organic emission sources. Generally they can be applied to organic emission sources having a well defined and contained emission stream, such as chemical, metallurgical, surface coating, and agricultural processes; they cannot readily be applied to sources having scattered and uncontained organic emissions, such as burning landfills and coal refuse piles, pipe leaks, and uncontained vents. Among the emission sources to which they are applied are:

- Animal-matter rendering
- Chemical milling
- Coffee roasting
- Degreasing operations
- Dry Cleaning
- Electroplating
- Fertilizer plants
- Fiberboard drying and curbing
- Fish canneries
- Food processing equipment
- Frit smelters
- Glass manufacture
- Insecticide manufacture
- Meat smokehouses
- Oil and solvent refining
- Paint-bake ovens
- Phosphoric acid manufacturing
- Resin kettels
- Rotogravuring
- Soap and synthetic detergent industries
- Sulfuric acid manufacturing
- Varnish cookers
- Wire-coating process

With such widespread use of afterburners, it is important to national and local air quality efforts to understand just how successful afterburners are at controlling emissions. Unfortunately, the overall performance of afterburners has been frequently based on limited research studies, or on tests of new and/or well-tuned units. These tests measure afterburner performance of units operating at peak efficiency. Consequently, efficiency values above 90 percent or 95 percent, and sometimes as high as even 99 percent, are usually reported (1-8). However, there remains the strong suspicion that performance of typical in-service afterburners is not as good as that reported in the idealized tests. Because afterburners are not income-producing devices, it is suspected that their maintainence, etc., may receive less than adequate attention.

This program considers the extent of application of afterburners, and reports on afterburner performance based on results of a limited number of afterburner emission tests conducted by local air pollution control agencies.

## SUMMARY

It has been shown that afterburners are candidate organic emission control devices for application to emission sources emitting almost 30 percent of the volatile nonmethane organic emissions generated by man-related stationary sources. Further, the analysis of afterburner efficiency conducted as a part of this program shows that typical in-service afterburners are likely to be considerably less efficient than are the well-tuned units used in the studies normally reported in literature.

It has been shown that the error in estimating volatile nonmethane organic emissions due to the demonstrated poorer performance of afterburners is probably not significant on a national basis (causing an error of about 2 percent), but may be very significant on a local basis (causing an error that may exceed 27 percent). Hence, at least as it affects local areas, it is important that the effort to understand and interpret the actual performance of in-service afterburners be continued. Also, a research program to obtain emissions data on typical in-service afterburners is recommended.

## REVIEW OF AIR POLLUTION REGULATIONS FOR CONTROLLING HYDROCARBONS FROM STATIONARY POINT SOURCES

This review covers significant hydrocarbon sources that would require control methods or the application of control devices. It excludes mobile sources, such as automobiles, whose control is primarily the responsibility of the federal motor vehicle control program. Automobiles collectively are a major source of hydrocarbons, but individually they are a small source. Dry cleaning establishments are also small individual sources, although their collective emissions of hydrocarbons is large. Both automobiles and small dry cleaners are classified as area sources. There is some state legislation for these sources, much of it associated with Transportation Control Plans.

The objective of the present discussion is the review of state and local emission standards set for significant industrial sources of hydrocarbons. Hydrocarbon emission standards are important in that they have an impact on (1) the need for afterburners or other techniques, (2) the performance of installed afterburners, and (3) the availability of emissions test data. Obviously, if control devices are not required, or if performance testing is not required, or state or local agency will have little test data on afterburners.

Source material for this review was primarily the compilation of State Air Laws collected and copyrighted by The Bureau of National Affairs, Incorporated, in connection with their publication of the "Environment Reporter". The compilation that was used is reasonably up to date. However, it should be recognized that air pollution regulations are continually being revised and, thus, the regulations cited in this report may become dated.

## Ambient Standards for Hydrocarbons

Most state standards for ambient concentrations of hydrocarbons are identical to the National Ambient Air Quality Standard:

> 160 $\mu g/m^3$ (0.24 ppm) average between 6 and 9 AM not to be exceeded more than once a year.

This is both the primary and secondary standard and actually applies only to non-methane hydrocarbons. There are several state standards which differ from the Federal standard. For instance:

| State | Maximum 6-9 AM Average ($\mu g/m^3$) |
|---|---|
| Delaware | 131 |
| Hawaii | 100 |
| Ohio | 126 |

Hawaii does not specify 6-9 AM, but calls for the average to be taken over a "3-hour morning period". Ohio has a 24-hour standard of 331 $\mu g/m^3$.

Conversely, there is Vermont which has rejected the national standard citing that there are differences between the working and measurement techniques for total hydrocarbons and non-methane hydrocarbons that need to be resolved by the Federal Government.(9)

## Emission Standards for Hydrocarbon Sources

Examination of state regulations pertaining to limitations on hydrocarbon emissions from point sources showed that 55 percent of the states have some form of regulation. As might be expected, there was considerable similarity between the standards as written by the various states. There are basically two types of standards. One type of regulation covers equipment and/or processes using or applying organic solvents and other specific types of point sources of hydrocarbon emissions. The other type applies to the storage and transfer of petroleum products.

States with the organic solvent standards generally include definitions of such terms as volatile organic compounds, organic materials, photochemically reactive materials, and organic solvents. Several of these states have lists or detailed descriptions of what substances they consider to be photochemically reactive. Also, these standards often include a list of operations for which the standard is not to be applied.

For a few states the standards apply to only certain areas within the states (generally Air Quality Control Regions), where hydrocarbon emissions and photochemical oxidants are considered a problem. An example of this is the Mobile area of Alabama.

Los Angeles Regulations

The Los Angeles Air Pollution Control District has adopted hydrocarbon emission regulations, especially Rule 66, which have been used as the basis for many state regulations. The pertinent Los Angeles regulations are Rule 56--Storage of Petroleum Products, Rule 59--Oil Effluent Water Separator, Rule 61--Gasoline Loading into Tanks, Trucks and Trailers and Organic Liquid Loading, and Rule 66-Organic Solvents. A copy of the several Los Angeles rules which regulate emissions of hydrocarbons is included as Appendix A to this report.

Emission Standards for Equipment Discharging Organic Solvents to the Atmosphere

Of the 50 states, 15 have regulations for organic solvent usage. Regulations concerning emissions of organic solvent often have derived (or copied) from the Los Angeles Air Pollution Control Board's Rule 66. These regulations define three classes of organic solvents; namely:

1) Organic solvents which come in contact with flame or are baked, heat-cured, or heat polymerized in the presence of oxygen.

2) Photochemically reactive solvents (as defined by the regulation).

3) Non-photochemically reactive organic solvents.

The Rule 66 emission standards of

1) 15 pounds per day or 3 pounds per hour for heated organic solvents

2) 40 pounds per day or 8 pounds per hour for photochemically reactive solvents, and

3) 3000 pounds per day or 450 pounds per hour for non-photochemically reactive solvents

are the numbers used by most states that have organic solvent standards. Table 1 lists local and state regulations applying to general sources of organic emissions. Some states do not differentiate between the three classes of organic emissions and use one set of numbers (either 15 and 3, or 40 and 8) for more than one class of emissions. Other agencies vary the allowable emissions for one or more classes of emissions (compared to Rule 66), e.g., Connecticut's standard for non-photochemically reactive solvents is 800 lbs/day and 160 lbs/hour.

Where control efficiency is specified, and generally it is, the required efficiency is 85 percent. Wisconsin identifies flame incineration, catalytic incineration, or smokeless flares as required methods of control, but most state regulations allow adsorption or incineration with the additional requirement that the incineration should convert at least 90 percent of the carbon in the organic material to carbon dioxide.

In most regulations the phrase "articles, machines, equipment, or other contrivances designed for processing a continuous web, strip, or wire which emit organic materials" is used to describe the type of facility for which the standard is applicable. All have some operations that are excluded, the most frequently mentioned being the spraying of insecticides,

TABLE 1. EMISSION REGULATIONS APPLYING TO GENERAL SOURCES OF ORGANIC EMISSIONS

| Regulations for general sources or organic emissions | Ala., Mobile Co. Calif., South Coast AQCD Massachusetts, Boston Area New York, New York City Area Ohio | Arizona, except as noted Nevada | Arizona, Maricopa Co. | Arizona, Pima Co. | Calif., Bay Area AQCD | Colorado | Connecticut | District of Columbia | Illinois |
|---|---|---|---|---|---|---|---|---|---|
| (a) Organic emissions from processes involving heating | | | | | | | | | |
| - Emission limit, lb/hr | 3 | | | 3 | | 3 | 3 | 3 | |
| - Emission limit, lb/day | 15 | | 15 | 15 | | 15 | 15 | 15 | |
| - Emission limit, ppm total carbon | | | | | 300 | | | | |
| - Reduction of emissions, percent | 85 | | | | 85 | 85 | 85 | 85 | |
| - Burn emission; 1300 F for 0.3 seconds | | | | | | | | | |
| - Reasonable and proper control | | X | | | | | | | |
| (b) Photochemically reactive solvents (unheated) | | | | | | | | | |
| - Emission limit, lb/hr | 8 | | | 3 | | 8 | 8 | 3 | 8 |
| - Emission limit, lb/day | 40 | | 40 | 15 | | 40 | 40 | 15 | |
| - Emission limit, ppm total carbon | | | | | 300 | | | | |
| - Reduction of emissions, percent | 85 | | | | | 85 | 85 | 85 | 85 |
| - Burn emission, 1300 F for 0.3 seconds | | | | | | | | | |
| - Reasonable and proper control | | X | | | | | | | |
| (c) Non-photochemically reactive solvents (unheated) | | | | | | | | | |
| - Emission limit, lb/hr | | | | | | 450 | 160 | 8 | |
| - Emission limit, lb/day | | | | | | 3000 | 800 | 40 | |
| - Emission limit, ppm total carbon | | | | | 300 | | | | |
| - Reduction of emissions, percent | | | | | | 85 | 85 | 85 | |
| - Reasonable and proper control | | X | | | | | | | |

TABLE 1. (Continued)

| Regulations for general sources or organic emissions | Indiana Wisconsin | Kentucky, Louisville & Covington Area | Louisiana | Maryland, eight urban counties (new sources) | Maryland, eight urban counties (existing sources) | North Carolina | Oklahoma | Pa., Allegheny Co. | Pa., Philadelphia Co. Virginia, Wash., D.C. area | Rhode Island | Tennessee | Texas, 18 counties |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) Organic emissions from processes involving heating | | | | | | | | | | | | |
| - Emission limit, lb/hr | 3 | 8 | 3 | | | | 3 | 7 | | | | |
| - Emission limit, lb/day | 15 | 40 | 15 | 15 | 200 | 40 | 15 | 100 | 15 | 40 | | |
| - Emission limit, ppm total carbon | | | | | | | | | | | | |
| - Reduction of emissions, percent | 85 | 85 | | 85 | 85 | 85 | 85 | 85 | 95 | | | |
| - Burn emission; 1300 F for 0.3 seconds | | | | | | | | | | | | X |
| - Reasonable and proper control | | | | | | | | | | | X | |
| (b) Photochemically reactive solvents (unheated) | | | | | | | | | | | | |
| - Emission limit, lb/hr | 3 | 8 | 3 | | | | 8 | | | | | |
| - Emission limit, lb/day | 15 | 40 | 15 | 40 | 200 | 40 | 40 | | 40 | 100 | | |
| - Emission limit, ppm total carbon | | | | | | | | | | | | |
| - Reduction of emissions, percent | 85 | 85 | | 85 | 85 | 85 | 90 | | 85 | | | |
| - Burn emission, 1300 F for 0.3 seconds | | | | | | | | | | | | X |
| - Reasonable and proper control | | | | | | | | | | | X | |
| (c) Non-photochemically reactive solvents (unheated) | | | | | | | | | | | | |
| - Emission limit, lb/hr | | | | | | | 450 | | | | | |
| - Emission limit, lb/day | | | | | | | 3000 | | | | | |
| - Emission limit, ppm total carbon | | | | | | | | | | | | |
| - Reduction of emissions, percent | | | | | | | 90 | | | | | |
| - Reasonable and proper control | | | | | | | | | | | X | |

pesticides, or herbicides--these are not considered to be a point source. Table 2 is a list of other exclusions from the organic solvent standard. Since the operations listed in Table 2 are not common to all state regulations it can be assumed that in some states these operations come under the organic solvent standards.

Hydrocarbon Emission Standards for Specified Sources

In addition to general hydrocarbon emission regulations, half the states have enacted standards restricting the emissions of hydrocarbons from selected processes or pieces of equipment. Ethylene processing or producing plants are singled out for special standards more frequently than any other source. For some sources the standard is directed at other pollutants, e.g., visible particulate,as well as to the hydrocarbons in the waste stream.

Generally these standards are only a requirement that the waste gas stream be incinerated with the most frequent phrase being "shall be burned at 1300 degrees F (704 C) for 0.3 seconds or longer". However, a few states also include numerical limitations on the emissions, such as parts per million equivalent methane (Illinois), or pounds per day (Kansas and others).

TABLE 2. OPERATIONS EXCLUDED FROM ORGANIC SOLVENT LAW BY ONE OR MORE STATES

1. Manufacture of organic solvents.
2. Paint spray booths.
3. Textile industry use of organic solvents.
4. Blending of oils.
5. Operations involving specified crude oils.
6. Tar heaters.
7. Manufacturers who reduce organic material to 20 percent or less of total volume.
8. Operations employing halogenated hydrocarbons and perchloroethylene.
9. Operations employing trichloroethylene.
10. Operations using selected solvents.
11. Operations using unreactive organic compounds.

Some of the state standards for hydrocarbon sources should be mentioned for their uniqueness. Oklahoma requires that fuel burning and refuse burning equipment be operated to minimize hydrocarbon emissions and lists several suggested methods for doing this. Oregon deviates from the 1300 F incineration temperature, specifying 1500 F for emissions from hardboard tempering operations and 1200 F for vapors from rendering plants. For veneer driers in the veneer and plywood industry, Oregon directs that controls of condensible hydrocarbons and other emissions are to be of the degree needed to reduce the blue haze from this operation to less than 10 percent opacity.

Table 3 presents a list of hydrocarbon emission sources specifically designated by states for control. While some source or state standard may have been inadvertently excluded from this list, the coverage indicates fairly completely the extent of the standards for specific sources.

## Comments on 1300 F, 0.3 Second Residence Time as Basis for Organic Emission Regulations

Because certain afterburner design criteria, generally a temperature of 1300 F and a residence time of 0.3 seconds, frequently are sited as afterburner regulations, some review of these criteria for the destruction of various organic materials is in order.

Lee, Hansen, and McCauley[10] recently have published a procedure for calculating the destruction of 15 organic species in terms of percent remaining of a species after reaction at various temperatures and times. Using their procedure and data, the fraction remaining after incineration at 1300 F for 0.3 seconds was calculated for the 15 species they considered. Results of this calculation are tabulated in Table 4.

Examining the results tabulated in Table 4, it is seen that 1300 F and 0.3 seconds is completely ineffective for incinerating methane, ethene, propylene, and benzene; is moderately effective (50 to 90 percent destroyed) for incinerating propane, ethylene, toluene, ethanol, acrylonetrile, and vinyl chloride; and is quite effective (over 99 percent) for incinerating butane, acrolein, ethyl acrylate, triethylamine, and 1.2 dichloroethane. Thus,

TABLE 3. STATE HYDROCARBON EMISSION STANDARDS FOR SPECIFIC POINT SOURCES

| Source | Applicable States | Standard* |
|---|---|---|
| 1. Foundry cupolas | Connecticut | B |
| | Minnesota | C |
| | Texas | B |
| 2. Degreasing operations | California | 85% control |
| | Colorado | 40 lbs/day |
| 3. Ethylene Processing and Manufacturing | Indiana | B |
| | Kentucky | B |
| | Louisiana | B |
| | Ohio | B |
| | Oklahoma | B |
| | Pennsylvania | B |
| | Texas | B & 100 lbs/day |
| | Virginia | B & 40 lbs/day |
| 4. Vapor Blow-Down | Oklahoma | F |
| | Virginia | F & 40 lbs/day |
| | Illinois | F & 10 ppm methane |
| | Indiana | F |
| | Kansas | B & 50 lbs/day |
| 5. Rendering Plant | Idaho | Vapors passed through condenser then C. |
| | Oregon | C |
| 6. Catalyst regenerator | Illinois | 100 ppm equivalent methane. |
| | Indiana | Burned in after-burners or equivalent. |
| | Texas | B |
| 7. Petroleum fluid coker | Illinois | 100 ppm equivalent methane. |
| | Indiana | Burned in afterburner or equivalent. |
| | Texas | B |

* B denotes bunning of emission at temperature of at least 1300 F for 0.3 second or longer.
C denotes burning of emission at temperature of at least 1200 F for 0.3 second or longer.
F denotes burning by smokeless flares

TABLE 3. CONTINUED

| Source | Applicable States | Standard |
|---|---|---|
| 8. Petroleum manufacturing waste gas stream | Illinois | 100 ppm equivalent methane. |
| | Texas | B |
| 9. Gasification plant | New Mexico | Limits on storage and associated equipment. |
| 10. Oil exploration, refining, processing, etc. | North Dakota | Organic compounds to be incinerated if they contain hydrogen sulfide. |
| 11. Fuel burning | Oklahoma | Operated to minimize organic emissions. |
| 12. Refuse burning equipment | Oklahoma | Operated to minimize organic emissions. |
| 13. Veneer drier | Oregon | 10% opacity for the flame. |
| 14. Hardboard tempering operations | Oregon | All gases and vapors to be burned at 1500 F for 0.3 seconds or the equivalent. |
| 15. Byproduct coke oven gas | Pennsylvania | Must be burned (limits on hydrogen sulfide content of the emission). |
| 16. Process vent waste stream containing designated carbon compounds | Texas | Burn at 1300 F in smokeless flare or direct flame incinerator. |

TABLE 3. CONTINUED

| Source | Applicable States | Standard |
|---|---|---|
| 17. Incinerator. | Washington | 100 ppm of total carbonyls. |
| 18. Enclosed paint spraying operation | Wisconsin | 30 lbs/day, 6 lbs/hr, Or 85% control. |
| 19. Polymer synthesis process | Colorado | B with direct-flame afterburner or equally effective device. |
| 20. Basic oxygen furnace | Texas | B |
| 21. Blast furnace | Texas | Burn in smokeless flare or used for heating. |

TABLE 4. CONCENTRATION RATIO AFTER 0.3 SEC AT 1300 F, BASED ON REFERENCE 10

| Pollutant | Ignition Delay Time, Sec* | Final Concentration / Initial Concentration |
|---|---|---|
| Methane | 0.379 | 1.00 |
| Ethane | 0.570 | 1.00 |
| Propane | 0.1282 | .444 |
| Ethylene | 0 | .163 |
| Propylene | 0.341 | 1.00 |
| Butene | 0.0790 | $3.09 \times 10^{-4}$ |
| Benzene | 0.276 | 0.937 |
| Toluene | 0.1514 | 0.452 |
| Acrolein | 0 | $<10^{-10}$ |
| Ethanol | 0.1500 | 0.240 |
| Ethyl Acrylate | 0 | $<10^{-10}$ |
| Acrylonitrile | 0.050 | 0.300 |
| Triethylamine | 0.100 | $<10^{-10}$ |
| Vinyl Chloride | 0 | 0.468 |
| 1,2-Dichloroethane | 0.001 | $9.16 \times 10^{-5}$ |

* Ignition delay times greater than 0.3 seconds preclude ignition within an afterburner providing 1300 F for 0.3 seconds; hence, there is no emission reduction for these cases.

a general hydrocarbon emission regulation calling for incineration at 1300 F for 0.3 seconds may be effective or ineffective for different sources. Due to this uncertainty, such regulations seem ill advised.

It should be pointed out that the values calculated by the procedure given in Reference 2 only refer to destruction of the original species--that is, they do not predict effectiveness for converting carbon in pollutants to CO or $CO_2$. Hence, they ignore the possible formation of other undersirable species during the incineration process.

## Standards for Storage and Transfer of Petroleum Products

Twenty eight states have regulations covering petroleum products storage facilities. The standards may also extend to transfer operations, to pumps and compressors, and to water separation from petroleum products. Los Angeles Rules 56, 59 and 61 are typical of these standards. The standards specify equipment such as floating roof tanks, vapor lines, and mechanical seals for pumps. Each state having a storage tank standard designates the smallest tank size to which the standard applies. This designated size will vary from state to state. Many of the storage tank standards have been imposed as a result of the U.S. EPA New Source Performance Standard for storage tanks.

Emissions from storage and transfer of petroleum products are not prime candidates for control with afterburners. This is due to the widely scattered and uncontained nature of the emission sources. Thus, these emission sources receive little attention in the remainder of this report. However, they are included for the sake of completeness.

## HYDROCARBON POLLUTANT EMISSIONS AND THEIR POTENTIAL FOR CONTROL

An extensive summary of hydrocarbon pollutant emissions in the U.S., and their potential for reduction, has been prepared by others[11] The authors of Reference 11considered all types of controls including modification of processes, changes in process material (e.g., replace solvent-based paints with water-based paints), and the elimination of sources (e.g., eliminating open burning). The authors estimated the potential reduction of hydrocarbon emissions that could be achieved through the use of all control techniques.

The application of hydrocarbon control techniques considered in Reference 11 was reviewed to identify the hydrocarbon emission reduction that could be achieved by the application of afterburners, or fume incinerators. From these data, estimates were made of the national impact of the widespread utilization of afterburners on those processes for which afterburners are viable emission control devices. The following paragraphs describe this evaluation.

### Tabulation of U. S. Hydrocarbon Emissions and Impact of Control Devices

All U. S. hydrocarbon emission sources were divided into 13 major emission source categories in Reference 11, as follows:

I. Fossil Fuel Extraction
II. Fossil Fuel Processing
III. Fossil Fuel Transportation, Storage, and Distribution
IV. Fossil Fuel Refining
V. Fossil Fuel Combustion
VI. Fossil Fuel Feedstock Chemical Processing
VII. Noncombustion Organic Chemical Utilization
VIII. Agricultural and Forest Products

IX. Open Sources

X. Natural Sources

XI. Solid Waste Disposal

XII. Municipal Sewage Disposal

XIII. Other Sources

Table 5 lists the principal hydrocarbon emission sources that were considered within each of the above categories.

For the present program, each hydrocarbon emission source category listed above was evaluated to answer two questions.

1. How much of the total U.S. hydrocarbon emissions could be controlled with the application of air emission control devices and techniques short of elimination of sources?

2. How much of the total U.S. hydrocarbon emissions could be controlled with afterburners?

Table 6 provides a summary of total U.S. hydrocarbon emissions and of results obtained with regard to Question 1--hydrocarbon emissions that could be controlled with the application of air pollution control devices and techniques, short of such actions as completely eliminating emission sources. Special mention should be made of the reasoning behind these estimates:

I. II. III. IV. VI. VII. VIII. Essentially all hydrocarbon emissions from these sources were considered to be controllable.

V. Fossil Fuel Combustion: the controllable fraction was considered to be those hydrocarbon emissions generated by internal combustion engines; hydrocarbon emissions from other combustion sources (e.g., boilers) were considered too low to consider the application of control devices.

IX. Open Burning Sources: hydrocarbon emissions from these sources were considered uncontrollable, except by elimination of open burning.

X. Natural Sources: hydrocarbon emissions from natural sources were considered uncontrollable.

XI. Solid Waste Disposal: the only source considered controllable was incinerators; open burning of refuse was considered uncontrollable, except by elimination.

XIII. Other Sources: this source category consists of destructive fires; hydrocarbon emissions from such fires were considered uncontrollable.

TABLE 5. PRINCIPAL SOURCES OF HYDROCARBON EMISSIONS OF THE AIR[11]

| Major Source Category | Principal Sources Within Category |
|---|---|
| I. Fossil Fuel Extraction | Coal Production |
| | Crude Oil & Associated Gas Production |
| | Natural Gas Extraction |
| II. Fossil Fuel Processing | Natural Gasoline Plants |
| | Coal Preparation Plants |
| III. Fossil Fuel Transportation, Storage, and Distribution | Crude Oil Storage |
| | Gasoline Service Station Automobile Filling |
| | Gasoline Service Station Underground Tank Filling |
| | Gasoline Bulk Station Storage |
| IV. Fossil Fuel Refining | Storage, Petroleum Refineries |
| | Blowdown, Petroleum Refining |
| | Process Drains and Waste Water Separators, Petroleum Refineries |
| | Fluid Catalytic Cracker Units, Petroleum Refineries |
| | Vacuum Jets, Petroleum Refineries |
| V. Fossil Fuel Combustion | Industrial Internal Combustion, Gas Fired |
| | Utilities, Coal Fired |
| | Industrial, Natural Gas Fired |
| | Industrial Internal Combustion, Oil Fired |
| | Industrial/Commercial, Fuel Oil Fired |
| VI. Fossil Fuel Feedstock Chemical Process | Ammonia |
| | Carbon Black |
| | Acrylonitrile |
| | Ethylene Dichloride |
| | Toluene |
| | Carbon Tetrachloride |
| VII. Noncombustion Organic Chemical Utilization | Rubber & Plastic Processing |
| | Paper & Paperboard Coating |
| | Sheet, Strip, and Coil Coating |
| | Miscellaneous Surface Coating |
| | Dry Cleaning |
| | Fabric Treatment |
| | Graphic Arts, Gravure |
| | Cast Iron Foundry Core Ovens |
| | Auto & Truck Coating |
| VIII. Agricultural and Forest Products | Pulp and Paper |
| | Wood Waste Combustion |
| | Beer Brewing |
| | Fruit and Vegetable Processing |
| | Tobacco |
| IX. Open Sources | Agricultural Field Burning for Land Clearance |
| | Prescribed Forest Burning |
| X. Natural Sources | Decomposition of Organic Material |
| | Living Plants |
| | Enteric Fermentation in Animals |
| XI. Solid Waste Disposal | Open Burning of Refuse |
| | Open Burning of Uncollected Urban Refuse |
| | Open Burning of Rural Refuse |
| | Methane from Decomposition in Dumps and Landfills |
| | Municipal Incineration |
| XII. Municipal Sewage Disposal | None--included as a category because of hydrocarbon emissions to water |
| XIII. Other Sources | Forest Wildfires |
| | Structural Fires |
| | Coal Refuse Fires |

TABLE 6. SUMMARY OF NATIONAL ORGANIC EMISSIONS FROM STATIONARY SOURCES AMENABLE TO EMISSION CONTROLS[a]

| Source Category | Total Atmospheric Emissions (Mt/yr)[b] | | | Uncontrolled Emissions from Sources Amenable to Air Pollution Controls (MT/yr) | | | Controllable Emissions from Sources Amenable to Controls (MT/yr) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Volatile Organics | Volatile Nonmethane Organics | Organic Particulates | Volatile Organics | Volatile Nonmethane Organics | Organic Particulates | Volatile Organics | Volatile Nonmethane Organics | Organic Particulates |
| I. Fossil Fuel Extraction[c] | 2,510,000 | - | - | 2,510,000 | - | - | 1,830,000 | - | - |
| II. Fossil Fuel Processing[c] | 1,716,400 | - | 7,300 | 1,714,000 | - | 7,300 | 1,030,000 | - | 3,650 |
| III. Fossil Fuel Transportation, Storage, & Distribution | 2,071,000 | 2,071,000 | 77,300 | 2,071,000 | 2,071,000 | 77,300 | 1,363,000 | 1,363,000 | 69,600 |
| IV. Fossil Fuel Refining | 2,173,500 | 2,173,500 | 269,000 | 2,173,500 | 2,173,500 | 269,000 | 1,400,000 | 1,400,000 | 243,600 |
| V. Fossil Fuel Combustion | 724,000 | 383,900 | - | 317,000 | 68,200 | - | 314,000 | 67,500 | - |
| VI. Fossil Fuel Feedstock Chemical Processing | 1,400,000 | 1,077,000 | 45,800 | 1,400,000 | 1,077,000 | 45,800 | 1,270,000 | 953,000 | 40,900 |
| VII. Noncombustion Organic Chemical Utilization | 3,529,000 | 3,529,000 | - | 3,529,000 | 3,529,000 | - | 2,868,000 | 2,868,000 | - |
| VIII. Agricultural & Forrest Products | 508,000 | 508,000 | 3,324,000 | 508,000 | 508,000 | 3,324,000 | 504,000 | 504,000 | 3,300,000 |
| IX. Open Burning Sources (agricultural & prescribed forest burning) | 3,010,000 | 3,010,000 | 973,000 | - | - | - | - | - | - |
| X. Natural Sources | 85,300,000 | 9,100,000 | 1,500,000 | - | - | - | - | - | - |
| XI. Solid Waste Disposal | 2,690,000 | 2,443,000 | 640,000 | 115,500 | 115,500 | 108,800 | 64,800 | 64,800 | 75,000 |
| XII. Municipal Sewage Disposal | - | - | - | - | - | - | - | - | - |
| XIII. Other Sources | 917,000 | 917,000 | 234,000 | - | - | - | - | - | - |
| | 106,548,900 | 25,212,400 | 7,040,400 | 14,338,000 | 9,542,200 | 3,832,200 | 10,643,800 | 7,220,300 | 3,654,100 |
| Total Emissions from Sources Amenable to Controls / Total Emissions from All Sources, percentage | | | | 13.5 | 37.8 | 54.4 | | | |
| Controllable Emissions from Sources Amenable to Controls / Total Emissions from Sources Amenable to Controls, percentage[d] | | | | | | | 74.2 | 75.7 | 97.4 |

(a) Data compiled from "Hydrocarbon Pollutants from Stationary Sources", EPA Report No. EPA 600/7-77-110, September, 1977.
(b) Mt/yr = metric tons per year.
(c) Emissions are mostly methane and considered a low pollution hazard.
(d) Mean control device efficiency.

The effectiveness of control devices was taken to be that assumed by the authors of the source document. Using these values, the emission values tabulated in Columns 4 through 9 of Table 6 were generated.

To answer Question 2, the possible impact of afterburners on hydrocarbon emissions, consideration must be given as to the types of emission sources for which afterburners are a viable control device. Afterburners are applicable only to emissions that can be fed into the afterburner via a duct. Hence, they apply to emission streams that already are contained within a duct, or that can be gathered (e.g., via a hood) and confined to a duct. Afterburners are not applicable to fugitive emissions that cannot practically be hooded.

Therefore, of the sources listed in Table 1, afterburners are applicable to

- a few sources in Category IV, Fossil Fuel Refining
- most sources in Category VI, Fossil Fuel Feedstock Chemical Processing
- most sources in Category VII, Noncombustion Organic Chemical Utilization
- some sources in Category VIII, Agricultural and Forest Products
- a few sources in Category XI, Solid Waste Disposal (specifically, to incinerators).

Considering the application of afterburners to the above sources, Table 7 provides a summary of results obtained with regard to Question 2--hydrocarbon emission that could be controlled with afterburner control devices. The material presented in Reference 1 was used in determining which sources could be controlled by afterburners, and in estimating the efficiency of afterburner control deivces.

Table 8 summarizes the results from both Tables 6 and 7 so that the possible application of all controls, and of afterburner controls, can easily be compared.

TABLE 7. SUMMARY OF NATIONAL ORGANIC EMISSIONS FROM STATIONARY SOURCES AMENABLE TO AFTERBURNER EMISSION CONTROLS[a]

| Source Category | Total Atmospheric Emissions (MT/yr)[b] | | | Uncontrolled Emissions from Sources Amenable to Control with Afterburners (MT/yr) | | | Controllable Emissions from Sources Amenable to Control with Afterburners (MT/yr) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Volatile Organics | Volatile Nonmethane Organics | Organic Particulates | Volatile Organics | Volatile Nonmethane Organic | Organic Particulates | Volatile Organics | Volatile Nonmethane Organics | Organic Particulates |
| I. Fossil Fuel Extraction[c] | 2,510,000 | - | - | - | - | - | - | - | - |
| II. Fossil Fuel Processing[c] | 1,716,400 | - | 7,300 | - | - | - | - | - | - |
| III. Fossil Fuel Transportation, Storage, & Distribution | 2,071,000 | 2,071,000 | 77,300 | - | - | - | - | - | - |
| IV. Fossil Fuel Refining | 2,173,500 | 2,173,500 | 269,000 | 117,000 | 117,000 | - | 116,000 | 116,000 | - |
| V. Fossil Fuel Combustion | 724,000 | 383,900 | - | - | - | - | - | - | - |
| VI. Fossil Fuel Feedstock Chemical Processing | 1,400,000 | 1,077,000 | 45,800 | 1,117,000 | 853,000 | 45,800 | 1,106,000 | 844,000 | 40,900 |
| VII. Noncombustion Organic Chemical Utilization | 3,529,000 | 3,529,000 | - | 3,162,000 | 3,162,000 | - | 2,666,000 | 2,666,000 | - |
| VIII. Agricultural & Forest Products | 508,000 | 508,000 | 1,124,000 | 171,000 | 171,000 | 582,000 | 367,000 | 367,000 | 576,000 |
| IX. Open Burning Sources (agricultural & prescribed forest burning) | 3,010,000 | 3,010,000 | 973,000 | - | - | - | - | - | - |
| X. Natural Sources | 85,300,000 | 9,100,000 | 1,500,000 | - | - | - | - | - | - |
| XI. Solid Waste Disposal | 2,690,000 | 2,443,000 | 640,000 | 115,500 | 115,500 | 108,800 | 64,800 | 64,800 | 75,000 |
| XII. Muncipal Sewage Disposal | - | - | - | - | - | - | - | - | - |
| XIII. Other Sources | 917,000 | 917,000 | 234,000 | - | - | - | - | - | - |
| | 106,548,900 | 25,212,400 | 7,040,400 | 4,882,500 | 4,618,500 | 736,600 | 4,319,800 | 4,057,800 | 691,900 |
| Total Emissions from Processes Amenable to Control with Afterburners / Total Emissions from All Sources, percentage | | | | 4.6 | 18.3 | 10.5 | | | |
| Controllable Emissions from Sources Amenable to Afterburner Controls / Total Emissions from Sources Amenable to Afterburners Controls, percentage[d] | | | | | | | 88.5 | 87.9 | 93.9 |

(a) Data compiled from "Hydrocarbon Pollutants from Stationary Sources", EPA Report No. EPA 600/7-77-110, September 1977.
(b) MT/yr = metric tons per year.
(c) Emissions are mostly methane and considered a low pollution hazard.
(d) Mean control device efficiency.

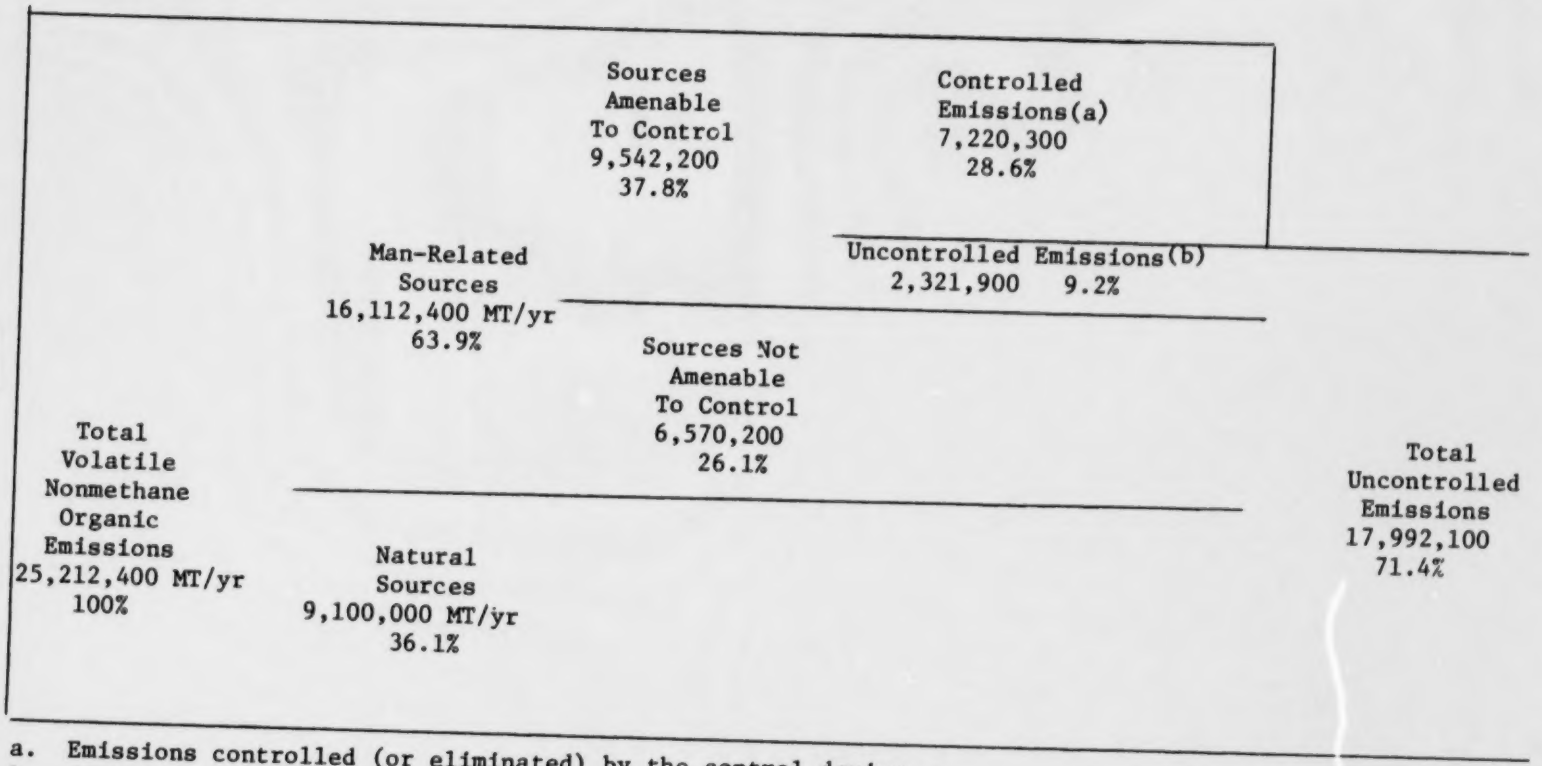
## U. S. Hydrocarbon Emissions and Impact of Control Devices

Based on the results summarized in Tables 6 through 8, it is estimated that 106,548,900 MT/yr(metric tons per year)of volatile organics and 7,040,400 MT/yr of organic particulate are emitted in the U.S. from stationary sources, including natural sources. Of the volatile organics total, 25,212,400 MT/yr are volatile nonmethane organics, which are considered more detrimental to the environment. Further examining the total emissions of organics, these emissions may be divided between natural and man-related sources as follows:

| | |
|---|---|
| Volatile organics | |
| Natural sources | 85,300,000 MT/yr (80.1 percent) |
| Man-related sources | 21,248,900 MT/yr (19.9 percent) |
| Volatile nonmethane organics | |
| Natural sources | 9,100,000 MT/yr (36.1 percent) |
| Man-related sources | 16,112,400 MT/yr (63.9 percent) |
| Organic Particulate | |
| Natural sources | 1,500,000 (21.3 percent) |
| Man-related sources | 5,540,400 (78.7 percent) |

Limiting the analysis to volatile nonmethane organics and organic particulates 62.2 and 45.6 percent, respectively, of these emissions originate from sources not considered amenable to the application of air pollution control devices (e.g., natural sources, open burning destructive fires, etc. The remainder, about 37.8 and 54.4 percent, respectively, of these emissions, originate from processes amenable to the application of emission control devices.

Figure 1 graphically illustrates the distribution of volatile nonmethane organics between natural sources and between man-related sources for which emission control devices are considered applicable or not applicable.




a. Emissions controlled (or eliminated) by the control device.
b. Emissions at outlet of control device.

FIGURE 1. NATIONAL VOLATILE NONMETHANE ORGANIC EMISSIONS FROM STATIONARY SOURCES

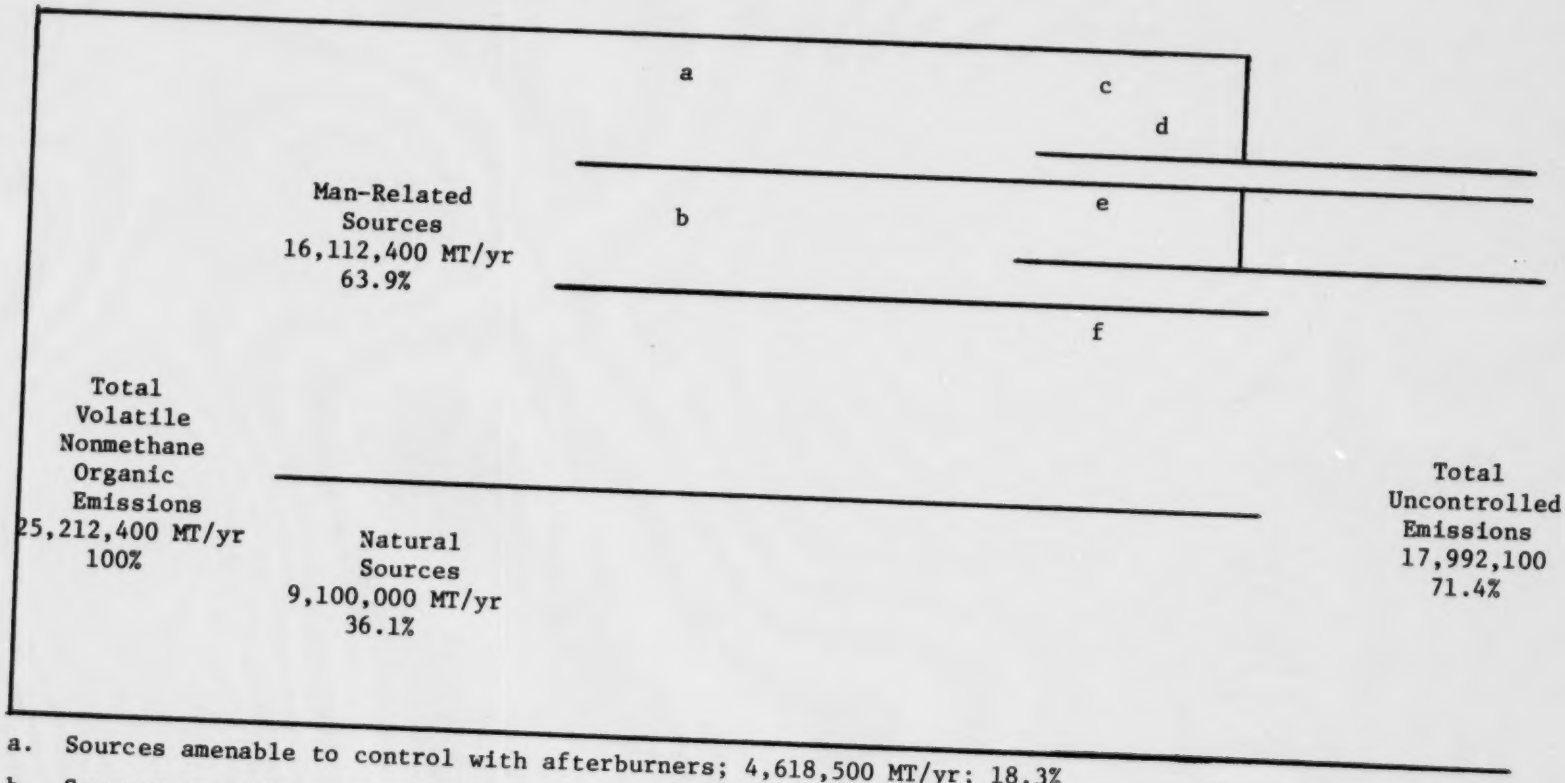
Further considering the volatile nonmethane organic emissions from sources for which control devices are applicable, it is estimated that about 75.7 percent of these emissions (28.6 percent of total volatile nonmethane organic emissions) could be controlled (eliminated) with the application of control deivces. The remaining 24.3 percent of such emissions are estimated to be uncontrolled (emitted due to control devices being less than 100 percent efficient). Figure 1 illustrates these data.

Based on the data shown in Table 8, afterburners are potentially applicable to sources representing 18.3 percent of all volatile nonmethane organic emissions. These sources emit 4,618,500 MT/yr of such emissions. By assuming an afterburner efficiency of 90 percent for nearly all afterburner applications , the authors of Reference 1 calculated a control efficiency of 87.9 percent for all sources amenable to the use of afterburners. Thus, for sources for which afterburners are applicable, the controlled (or eliminated) volatile nonmethane organic emissions would be 4,057,800 MT/yr, and the uncontrolled emissions (or emission at control device outlet) would be 560,700 MT/yr. Figure 2 repeats the data shown on Figure 1 but includes a further breakdown of emissions from controllable sources into sources that are controllable with afterburners and sources that are not controllable with afterburners.

Figure 3 and 4 show similar data as Figures 1 and 2, but for organic particulate emissions.

It should be recognized that afterburners would not be used on all emission sources to which they might be applied; other control deivces might be selected due to lower cost or better compatibility with the process. Thus, if afterburners were applied to one-half of those sources amenable to the application of afterburners, the national figures for sources with afterburner control would be:

| | Volatile Nonmethane Organics | Organic Particulates |
|---|---|---|
| inlet emissions | 2,309,250 MT/yr | 368,300 MT/yr |
| outlet emissions | 280,350 MT/yr | 22,350 MT/yr |
| controlled emissions | 2,028,900 MT/yr | 345,950 MT/yr |




a. Sources amenable to control with afterburners; 4,618,500 MT/yr; 18.3%

b. Sources amenable to control but not with afterburners; 4,923,700 MT/yr; 19.5%

c. Controlled emissions from sources amenable to control with afterburners; 4,057,800 MT/yr; 16.1%

d. Controlled emissions from sources amenable to control but not with afterburners; 3,162,500 MT/yr; 15.5%

e. Uncontrolled emissions from sources amenable to control with afterburners; 560,700 MT/yr; 2.2%

f. Uncontrolled emissions from sources amenable to control but not with afterburners, 1,761,200 MT/yr; 7.0%

FIGURE 2. NATIONAL VOLATILE NONMETHANE ORGANIC EMISSIONS FROM STATIONARY SOURCES SHOWING AFTERBURNER CONTROLLABLE EMISSIONS

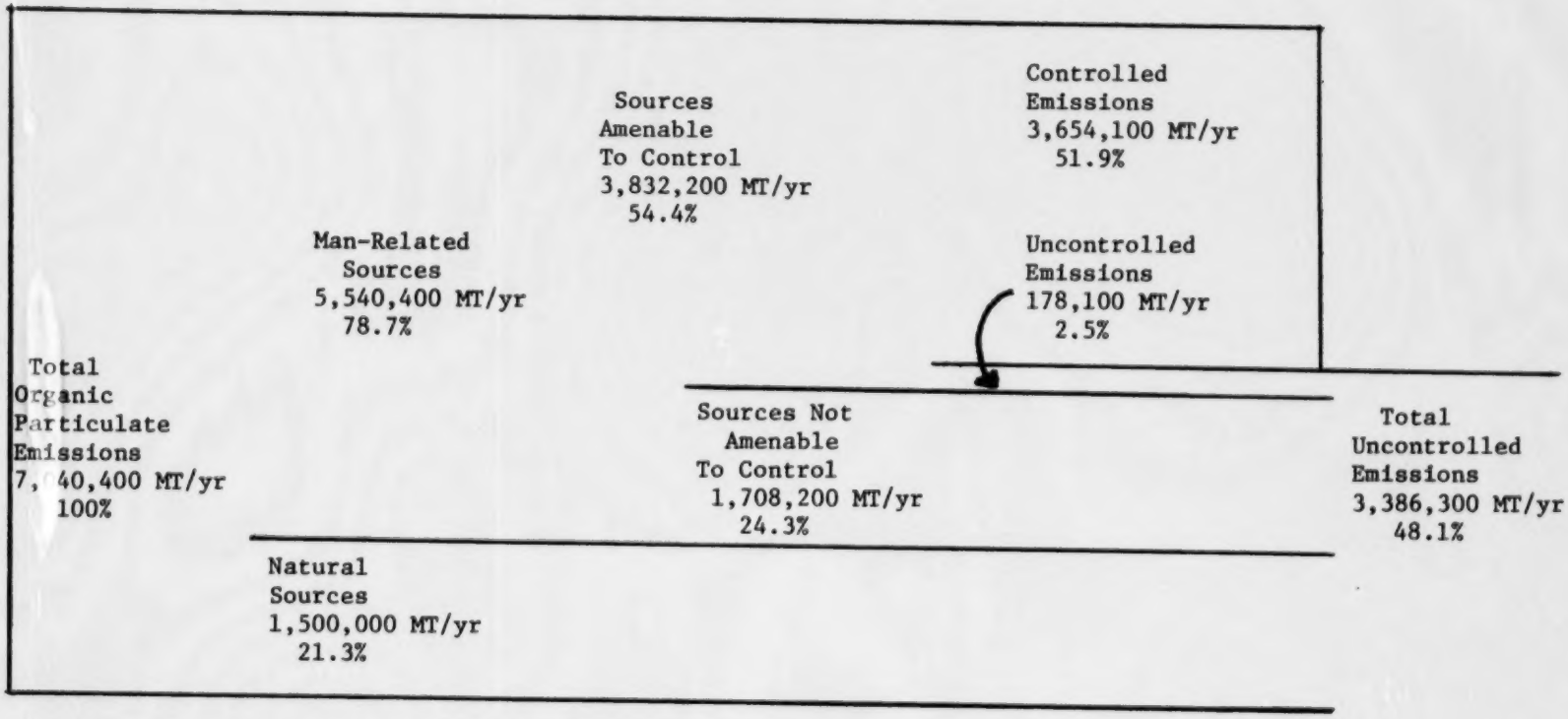
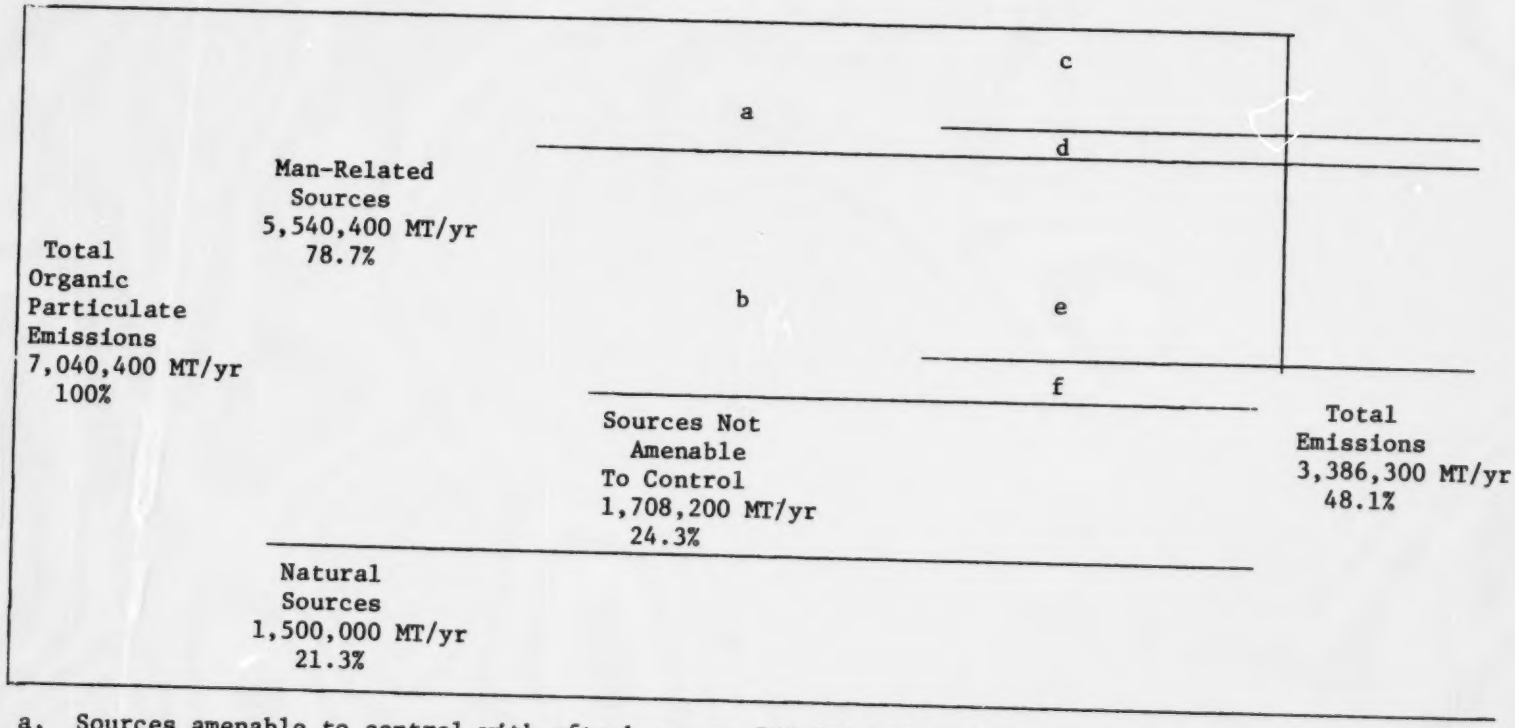



FIGURE 3. NATIONAL ORGANIC PARTICULATE EMISSIONS FROM STATIONARY SOURCES




a. Sources amenable to control with afterburners; 736,600 MT/yr; 10.5%
b. Sources amenable to control, but not with afterburners; 3,095,600 MT/yr; 44.0%
c. Controlled emissions from sources amenable to control with afterburners; 691,900 MT/yr; 9.8%
d. Uncontrolled emissions from sources amenable to control with afterburners; 44,700 MT/yr; 0.6%
e. Controlled emissions from sources amenable to control, but not with afterburners; 2,962,200 MT/yr; 42.1%
f. Uncontrolled emissions from sources amenable to control, but not with afterburners; 133,400 MT/yr; 1.9%

FIGURE 4. NATIONAL ORGANIC PARTICULATE EMISSIONS FROM STATIONARY SOURCES SHOWING AFTERBURNER CONTROLLABLE EMISSIONS

## COLLECTION AND EVALUATION OF AFTERBURNER TEST RESULTS

Most of the traditional literature concerning afterburner performance is of marginal value when trying to evaluate in-service afterburners. The literature generally contains reports on laboratory tests of full-scale or scaled-down afterburners, or field tests of newly installed afterburners. Thus, for these tests, the afterburners are well maintained and adjusted and, thus, are operating at peak efficiency. Also, if a manufacturer finds an afterburner gives a poor efficiency in a test, he will redesign the afterburner and publish results only for the improved afterburner. Thus, the typical published values for afterburners efficiency are in the 90 + percent range, i.e., 95, 98, 99 percent.[1-8] Afterburners are capable of that level of performance--but only if maintained, adjusted, and operated properly.

The interest of this program was not in the peak performance values of afterburners, but in the typical performance of afterburners. Thus, existing literature proved to be of little value and approaches were made to persons or agencies that might have typical afterburner operating data.

### Data Availability and Collection

The attempt to collect typical afterburner performance data centered around two types of data sources:

1. air pollution control agencies
2. afterburner manufacturers

#### State and Local Agencies

Contacts were made with a number of state or local air pollution control agencies. It was found that three conditions existed, defined as follows:

1. the agency had no regulations applicable to stationary hydrocarbon sources or afterburners
2. the agency had regulations regarding afterburners, but the regulations were design oriented--that is, they

These figures might be considered as "best guess" estimates of the likely impact of afterburners on total U. S. hydrocarbon emission--assuming that afterburners operate at the 90 to 95 percent efficiency values generally used by the authors of Reference 11.

required meeting a design criteria (e.g., 1300 F for 0.3 seconds) and not a performance criteria. Thus, emission tests were not conducted.

3. the agency had performance-based regulations and conducted afterburner performance tests.

Even for agencies fitting into the third category, except in a few cases where hydrocarbon emissions contribute to local air pollution problems, most agencies were not too concerned with afterburners--they felt that they had to use their limited funds and manpower on higher priority emission sources. Also, because afterburner emission test reports may contain proprietary data (chemical compositions and flow rates) agencies that had conducted afterburner emission tests were not always willing to share the data.

As a result we were able to identify only one state or local air pollution control agency that felt free to share test data from an appreciable number of afterburner emission tests.

Manufacturers

Two approaches were used to solicit afterburner performance data from manufacturers. First, 16 manufacturers were contacted. The purpose of the program was explained and performance data were requested. Little meaningful response was received. The attitude of afterburner manufacturers seemed to fall into one of two categories:

1. they knew what they were doing and were reluctant to share their knowledge to educate others
2. They did not appear to have a good understanding of afterburner design and the science of combustion--they just sold sheet metal.

Secondly, an approach was made to 5 manufacturers through their trade association, the Industrial Gas Cleaning Institute (IGCI). Battelle worked with IGCI to develop a questionnaire that IGCI could submit to member afterburner manufacturers; IGCI would then screen the responses to remove references to company names and forward the sterilized responses to Battelle. The responses were disappointing, little test data were given and, in fact, the responses suggest that manufacturers appeared to either not know the basis for their designs, or did not want to share their knowledge.

## Tabulation of Available Afterburner Test Results

A tabulation was made of the results of field tests on afterburners conducted by a local air pollution control agency. A total of 78 meaningful test result reports were identified from some 150 test reports received from the agency. (Many of the remaining test reports did not concern afterburners or were incomplete, e.g., they only reported outlet values.) These tests were conducted over a period of 14 years and do not appear to be limited to tests of newly installed units. In fact, some of these were made as a result of citizen complaints regarding the emission sources. Hence, these tests would appear to be somewhat more representative of in-service afterburner performance than are source-test data that are limited to newly installed units. However, these tests are not necessarily unbiased.

Table 9 lists pertinent data extracted from the 78 useful test reports. Where available, the Table 9 listing includes

- type of source
- type of afterburner
- afterburner operating temperature
- inlet stream values for
  - total organics
  - reactive organics
  - aldehydes
- outlet stream values for
  - total organics
  - reactive organics
  - aldehydes
- calculated afterburner efficiency values for
  - total organics
  - reactive organics

Caution must be exercised when referring to Table 9 for data regarding afterburner types and operating temperatures. There is no evidence that the agency differentiated between direct-flame and thermal afterburners. No thermal afterburners were listed; this may be because none were used on the sources tested. Conversely, some of the "flame" listings may have included thermal afterburners.

TABLE 9. AFTERBURNER PERFORMANCE TESTS

| Emission Source | Description of Afterburner[a] | Afterburner Operating Temperature[b], F | Organics in Inlet Stream | | | Organics in Outlet Stream | | | Afterburner Efficiency[e], percent | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics | Reactive Organics |
| 1. Coffee roaster | | | | 140 | | | 245 | | | -75 |
| 2. Web press | Flame | | 443 | 48 | | 605 | 142 | | -37 | -196 |
| 3. Lithographic oven | Catalytic | 580 | | 25.0 | | | 14.1 | | | 44 |
| 4. Lithographic oven | Catalytic | 690 | | 6.9 | | | 4.6 | | | 34 |
| 5. Resin production | Catalytic | | | 0.0035 | | | 0.045 | 4.2 | | -1190 |
| 6. Resin production | Catalytic | | | 0.015 | | | 0.26 | 35 | | -1630 |
| 7. Carbon dryer | Flame | | 75 | 0.6 | | 71.8 | 1.82 | 13 | 4 | -203 |
| 8. Lithographic oven | Catalytic | | 1845 | 81.6 | | 260 | 41. | 30 | 86 | 50 |
| 9. Coating Oven | Catalytic | | | 24.5 | | | 21.2 | 3.7 | | 14 |
| 10. Coating Oven | Catalytic | | 245 | 43.4 | | 71.4 | 19.5 | 3.4 | 71 | 55 |
| 11. Web press oven | Flame | | 0.195 | 0.104 | | 0.673 | 0.382 | 11.8 | -245 | -267 |
| 12. Coffee roaster | Flame | 1000 | 14.0 | 1.6 | | 35.6 | 10.9 | 42 | -154 | -581 |
| 13. Coffee roaster | Flame | 1100 | 17.1 | 2.65 | | 25.0 | 7.3 | 28 | -46 | -176 |
| 14. Coffee roaster | Flame | 1200 | 11.5 | 2.5 | | 40.4 | 10.7 | 30.5 | -251 | -328 |
| 15. Wire-coating line oven | | | > 3.4 | > 0.15 | | > 2.1 | > 0.10 | 2.2 | -- | -- |
| 16. Lithographic oven | Flame | 1300 | 1264 | 250 | | | | | | |
| 17. Lithographic oven | Flame | 1050 | 401 | 80 | | 716 | 290 | 105 | 43 | -16 |
| 18. Coating oven | Flame | 1050 | 1138 | 730 | | 496 | 178 | 65 | -24 | -123 |
| 19. Coating oven | Flame | 1200 | 1164 | 709 | | 826 | 588 | 43 | 27 | 20 |
| 20. Coffee roaster | Flame | | | 2.7 | | 486 | 429 | 13 | 58 | 40 |
| 21. Litho-coater drying oven | | 1400 | 1610 | 146 | 7 | < 45 | 8.3 | 35 | | -206 |
| 22. Barrell coater drying oven | Flame | 1180 | 460 | 90 | 7 | 32 | < 5 | 1 | > 97.2 | > 96.9 |
| 23. Sheet-metal coating drying oven | | 1200 | 1800 | 511 | 27 | 252 | 15 | 20 | 93.0 | 83 |
| 24. Sheet-metal coating drying oven | | 1400 | 1870 | 473 | 16 | < 23 | 178 | 174 | 86 | 65 |
| 25. Pail litho and coating drying oven | | 1240 | | | 17 | | < 15 | 2 | > 98.9 | > 96.8 |
| | | | | | | | | 1 | | |

TABLE 9. (Continued)

| Emission Source | Description of Afterburner[a] | Afterburner Operating Temperature[b], F | Organics in Inlet Stream | | | Organics in Outlet Stream | | | Afterburner Efficiency[e], percent | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics | Reactive Organics |
| 26. Pail mat line drying oven | | 1420 | | | 7 | | | 40 | | |
| 27. Painting-line drying oven | | 1000 | 410 | 76 | 25 | 248 | 123 | 49 | 40 | -62 |
| 28. Painting-line drying oven | | 1350 | 550 | 69 | 22 | < 12 | < 9 | 2 | > 97.8 | > 87 |
| 29. Coating-line drying oven | | 1280 | 835 | 370 | 8 | 23 | 10 | 4 | 97.2 | 97.3 |
| 30. Coating-line drying oven | | 1300 | 867 | 345 | 35 | 6 | 2 | 1 | 99.3 | 99.4 |
| 31. Metal-coating-line drying oven | Flame | 1050 | 269 | 98 | 39 | 107 | 46 | 37 | 60 | 53 |
| 32. Metal-coating-line drying oven | | | 184 | 12 | 16 | 110 | 16 | 28 | 40 | -33 |
| 33. Metal-coating-line drying oven | Flame | 1300 | 3556 | 2242 | | 30.5 | 10.7 | 8.2 | 99.1 | 99.5 |
| 34. Metal-coating-line drying oven | Flame | 1250 | 3343 | 2114 | | 259 | 42.1 | 21.5 | 92.3 | 98.0 |
| 35. Lithographic oven | | 1200 | 1445 | 986 | 28 | 789 | 580 | 122 | 45 | 41 |
| 36. Lithographic oven | | 1300 | 1476 | 1032 | 25 | 691 | 487 | 122 | 53 | 53 |
| 37. Phathalic anhydride tail gas | Flame | 1440 | 2299 | 498 | 49 | 370 | 925 | 1 | 84 | 81 |
| 38. Lithographic oven | Catalytic | | 382 | 104.8 | | 304 | 76.8 | 143 | 20 | 27 |
| 39. Asphalt Reactor | Flame | | 11,200 | 4515 | | 152 | 16.5 | 9.3 | 98.6 | 99.6 |
| 40. Paint kettle | Flame | | | | < 0.1 | | | 4 | | |
| 41. Lithographic oven | Catalytic | 702 | 956 | 572 | 13 | 470 | 78 | 59.2 | 51 | 75 |
| 42. Lithographic oven | Catalytic | | 1010 | 763 | 183 | 742 | 190 | 148 | 27 | 86 |
| 43. Litho-line oven | Catalytic | 700 | 140 | 11.3 | 14 | 175 | 17 | 27 | -25 | -50 |
| 44. Litho-line oven | Catalytic | 806 | 2337 | 11.3 | 4.7 | 573 | 145 | 104 | 76 | -118 |
| 45. Lithographic oven | Catalytic | 637 | 1716 | 1150 | 2.0 | 403 | 297 | 4.6 | 77 | 74 |

TABLE 9. (Continued)

| Emission Source | Description of Afterburner[a] | Afterburner Operating Temperature[b], F | Organics in Inlet Stream | | | Organics in Outlet Stream | | | Afterburner Efficiency[e], percent | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics | Reactive Organics |
| 46. Wire coater | Catalytic | | 168 | 132 | 81 | 6.3 | 4.8 | 49 | 96.2 | 96.4 |
| 47. Wire coater | Catalytic | | 99.7 | 86.7 | 87 | 1.65 | 1.35 | 0.45 | 98.3 | 98.4 |
| 48. Paint kettle | Flame | | 262 | 238 | Nil | 3.6 | < 2.4 | < 1 | 98.6 | > 99.0 |
| 49. Asphalt preheater and blower | Flame | | 562 | 223 | 482 | 46 | 15 | 7 | 91.9 | 93.2 |
| 50. Coffee roaster | Flame | 2600 | 180 | 34 | 89 | 20.4 | 2.4 | 9.6 | 89 | 92.9 |
| 51. Asphalt saturator | Flame | 939 | 86.2 | 3.6 | 0.5 | 55.9 | 28.9 | 25 | 35 | -703 |
| 52. Coffee roaster | Flame | 1810 | 68.6 | 17.2 | 60 | 12.8 | 2.5 | 11.8 | 81 | 86 |
| 53. Paint kettle | Flame | 1260 | 440 | 8 | Nil | 17.8 | 11.1 | 20 | 96.0 | -39 |
| 54. Drum-liner baking | Flame | 1000 | 179 | 11.7 | 11.5 | 68.9 | 10.8 | 22.5 | 62 | 8 |
| 55. Lithographic oven | Flame | 1290 | 3.7 | 0.915 | 1.5 | 6.4 | 0.1 | < 1 | -73 | 89 |
| 56. Pail line oven | | 1300 | 6.7 | 2.0 | 19 | 10.8 | 5.9 | 22 | -61 | -195 |
| 57. Drum painting line | Flame | 1140 | 101 | 4.7 | 12.5 | 7.15 | 5.3 | 20 | 92.9 | -13 |
| 58. Paint-line drying oven | | 677 | | | 7 | | | 0 | | |
| 59. Paint manufacture, open pot | Flame | | 0.31 | 0.03 | | 0.36 | 0.11 | | -16 | -267 |
| 60. Asphalt blower preheater | | | 385 | 167 | 1073 | 60.4 | 36.2 | 47 | 84 | 78 |
| 61. Asphalt saturator | Flame | | 4.99 | 0.30 | 1 | 3.66 | 0.21 | < 1 | 27 | 30 |
| 62. Lithographic oven | Flame | | 3040 | 2245 | | 267 | 183 | 19 | 91.2 | 91.8 |
| 63. Paint kettle | Flame | 1230 | | 72.8 | | 1.0 | 0.49 | 1.7 | | 99.3 |
| 64. Lithographic oven | Flame | | 481 | 114 | | 698 | 116 | 31 | -45 | -2 |
| 65. Lithographic oven | Flame | | 527 | 70 | | 416 | 34 | 17 | 21 | 51 |
| 66. Can coating: litho oven | Flame | | 1850 | 41.1 | | 410 | 152 | 116 | 78 | -270 |
| 67. Can coating: litho oven | Flame | | 6010 | 4980 | | 241 | 187 | 28 | 96.0 | 96.2 |
| 68. Lithographic oven | Direct flame | 1325 | 82.1 | 23.8 | | 88.6 | 4.2 | | -8 | 82 |
| 69. Lithographic oven | Catalytic | 630 | 801 | 651 | | 121 | 56 | 15 | 85 | 91.4 |
| 70. Can coating oven and overspray | | 1400 | 1631 | | | 141 | | | 91.4 | |

TABLE 9. (Continued)

| Emission Source | Description of Afterburner[a] | Afterburner Operating Temperature[b], F | Organics in Inlet Stream | | | Organics in Outlet Stream | | | Afterburner Efficiency[e], percent | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics[c], lb/day | Reactive Organics[d], lb/day | Aldehydes, ppm | Total Organics | Reactive Organics |
| 71. Can coating oven and overspray | | 1400 | 865 | 595 | | 45 | 2.8 | | 94.8 | 99.5 |
| 72. Metal-coating; finish oven | | 1200 | 4284 | 554 | | 1270 | 548 | 150 | 70 | 1 |
| 73. Can coating oven and overspray | Oil Fired | 1400 | 496 | | | 158 | | | 68 | |
| 74. Can coating oven and overspray | Oil Fired | 1400 | 589 | | | 49.8 | | | 91.5 | |
| 75. Lithographic oven | Direct Flame | 1350 | 83.7 | | | 3.4 | | | | |
| 76. Lithographic oven | Direct Flame | 1385 | 1646 | | | 46.9 | | | 97.2 | |
| 77. Can coating | | 1400 | 143 | | | 5.8 | | | 95.9 | |
| 78. Metal-coating; finish oven | | 1400 | 3788 | 2453 | | 123 | 84 | | 96.8 | 96.6 |

(a) Descriptions of afterburners were taken from test reports--some were incomplete. Presumably, all afterburners with operating temperatures over about 900 F are direct flame or thermal, and are not catalytic. No distinction was made between direct flame and thermal afterburners.

(b) Afterburner operating temperatures are as reported in test reports--some values are afterburner control settings, others may be measured values. The reliability of these values is questionable.

(c) Excluding methane.

(d) The definition of reactive organics may have varied during the period represented by these test results, but is generally taken to include olefins, carbonyls, phenols, and some aromatics.

(e) Afterburner efficiency = $\frac{\text{inlet value} - \text{outlet value}}{\text{inlet value}}$

In many cases, the afterburner type was not specified. It can be safely presumed that all afterburners with operating temperatures shown to be above about 1000 F would be direct flame or thermal afterburners.

Secondly, the recorded afterburner operating temperatures are suspect. In some cases the test reports mentioned that the recorded value was an afterburner control setting, not a measured value. Also, some reported values are obviously not meaningful, e.g., catalytic afterburner operating temperatures reported to be below 400 F.* Such values were not recorded in Table 9. As a whole the operating temperature values reported in Table 9 cannot be taken to be anything but a guide to true operating temperatures.

Unfortunately, the test reports summarized in Table 9 do not include two important values of interest--residence time and some measure of mixing. Without true operating temperatures and residence time and mixing data, little can be done in analyzing the important design aspects of afterburners.

Finally, the afterburner test reports did not include data on organic, or inorganic, particulate emissions. Apparently these emissions are controlled primarily by visibility or opacity regulations, rather than be measured emission values.

## Evaluation of Available Afterburner Test Results

The results of these tests reported in Table 9 were revealing in the poor afterburner performance recorded for many of the tests. Figure 5 shows the distribution of afterburner efficiencies based on emissions of total nonmethane organic species. The median efficiency was about 76 percent. About 38 percent of the tests gave afterburner efficiencies of 90 percent or

* Possibly exhaust gas temperatures were reported as operating temperatures.

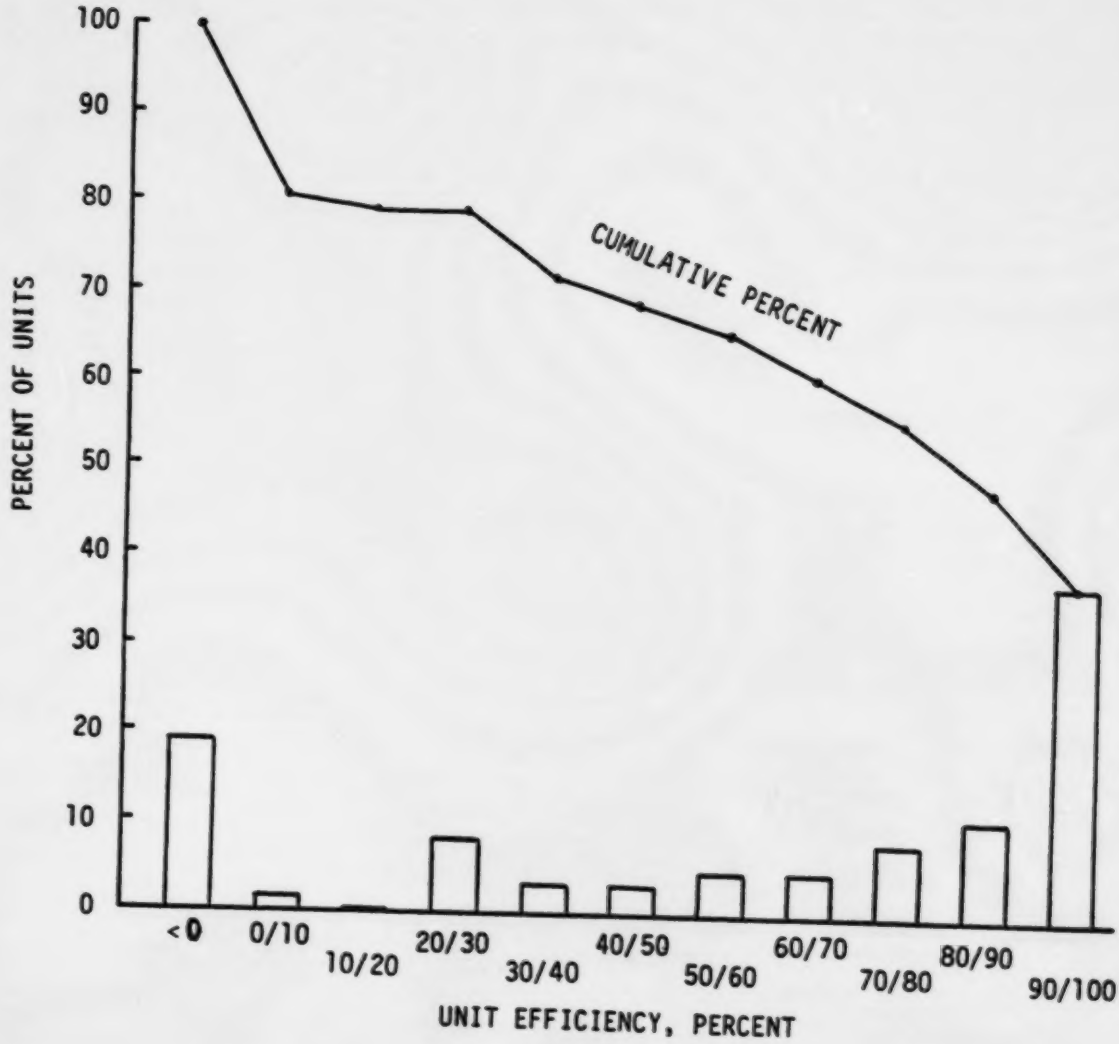



FIGURE 5. AFTERBURNER EFFICIENCY BASED ON TOTAL ORGANICS

higher. Another 18 percent of the tests gave efficiencies of 70 to 90 percent, and 25 percent of the tests gave efficiencies from 0 to 70 percent. Finally, 19 percent of the tests recorded afterburner efficiencies below zero percent, that is, outlet emissions exceeded inlet emissions.

Figure 6 shows the distribution of afterburner efficiencies for the same tests, but based on reactive organics. (Reactive organics include aromatics, phenols, carbonyls, and organic acids.) In general, afterburners efficiencies for reactive organics were lower than for total nonmethane organics; the median efficiency was only 50 percent. Twenty-nine percent of the tests gave efficiencies, based on reactive organics, or 90 percent or above; another 14 percent were in the 70 to 90 percent range; and 25 percent were in the 0 to 70 percent range. Finally, 33 percent of the tests gave negative efficiencies.

The negative efficiencies based on reactive organics are understandable in that, if reactive organics are only a small fraction of total organics at the inlet, an ineffective afterburner might convert a fraction of the nonreactive organics into reactive organic species and produce an apparent negative efficiency. A negative efficiency based on total nonmethane organics is not so easily explained. Efficiencies that are only slightly negative (as a number were) might be explained by limits in the accuracy of organic sampling and analysis and/or of flow rate measurements. However, efficiencies that are negative by more than about 30 percent cannot readily be explained in this way. A few afterburners were operating at off-design conditions (1000 F to 1100 F combustion zone temperatures versus the 1300 F to 1500 F normally used); such units may have been producing nonmethane organics from the fuel gas due to poor combustion conditions.

Figure 7 is a cross tabulation of afterburner efficiencies for both total nonmethane organics and reactive organics. From Figure 7, it can be seen that 30 tests (56 percent) reported about the same efficiencies for both total and reactive organics. Also, 16 tests (29 percent) showed a higher efficiency for controlling total nonmethane organics and 8 tests (15 percent) showed a higher efficiency for controlling reactive organics. The large degree of scatter of data shown in Figure 7 shows that if, both total

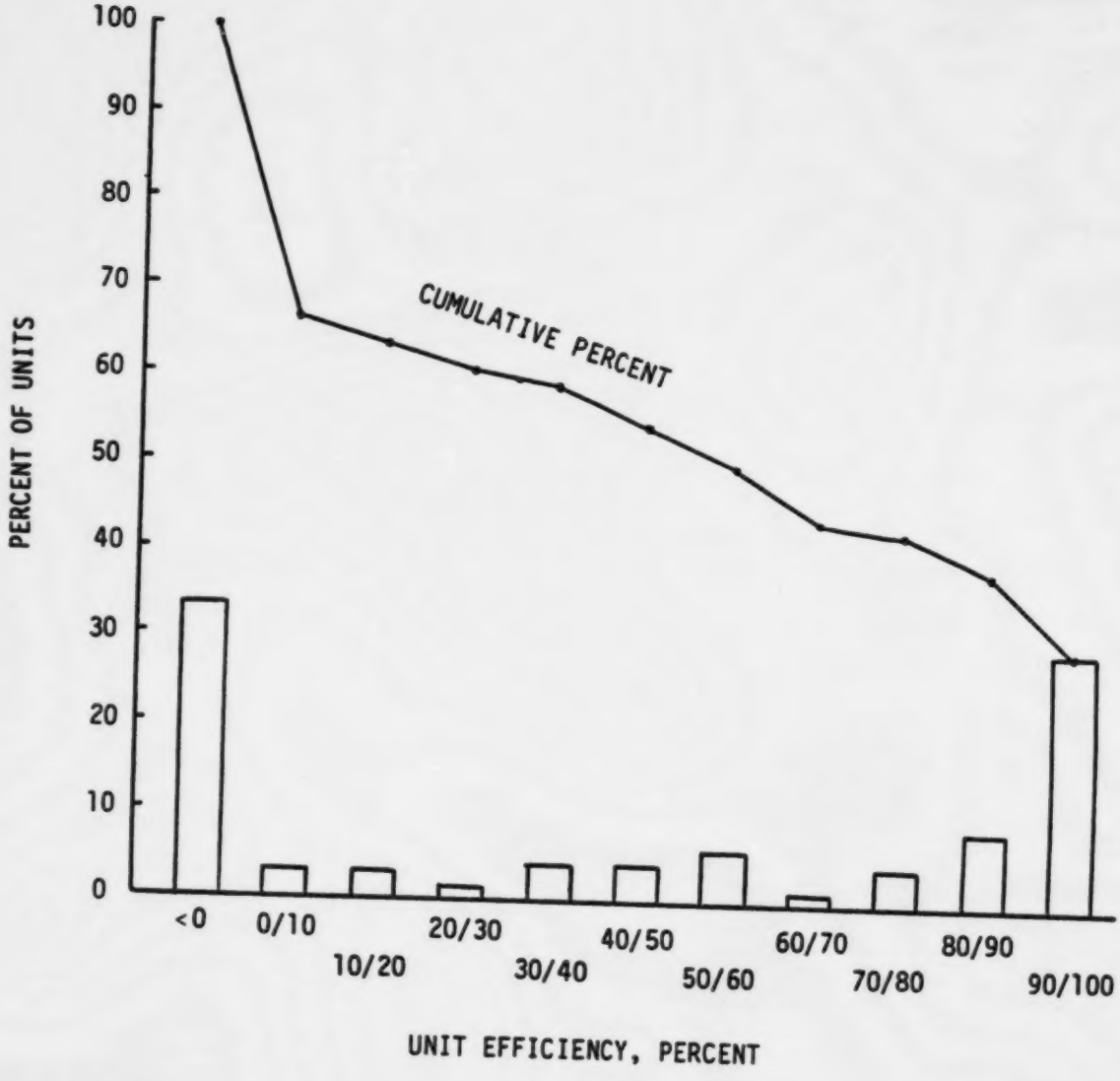



FIGURE 6. AFTERBURNER EFFICIENCY BASED ON REACTIVE ORGANICS

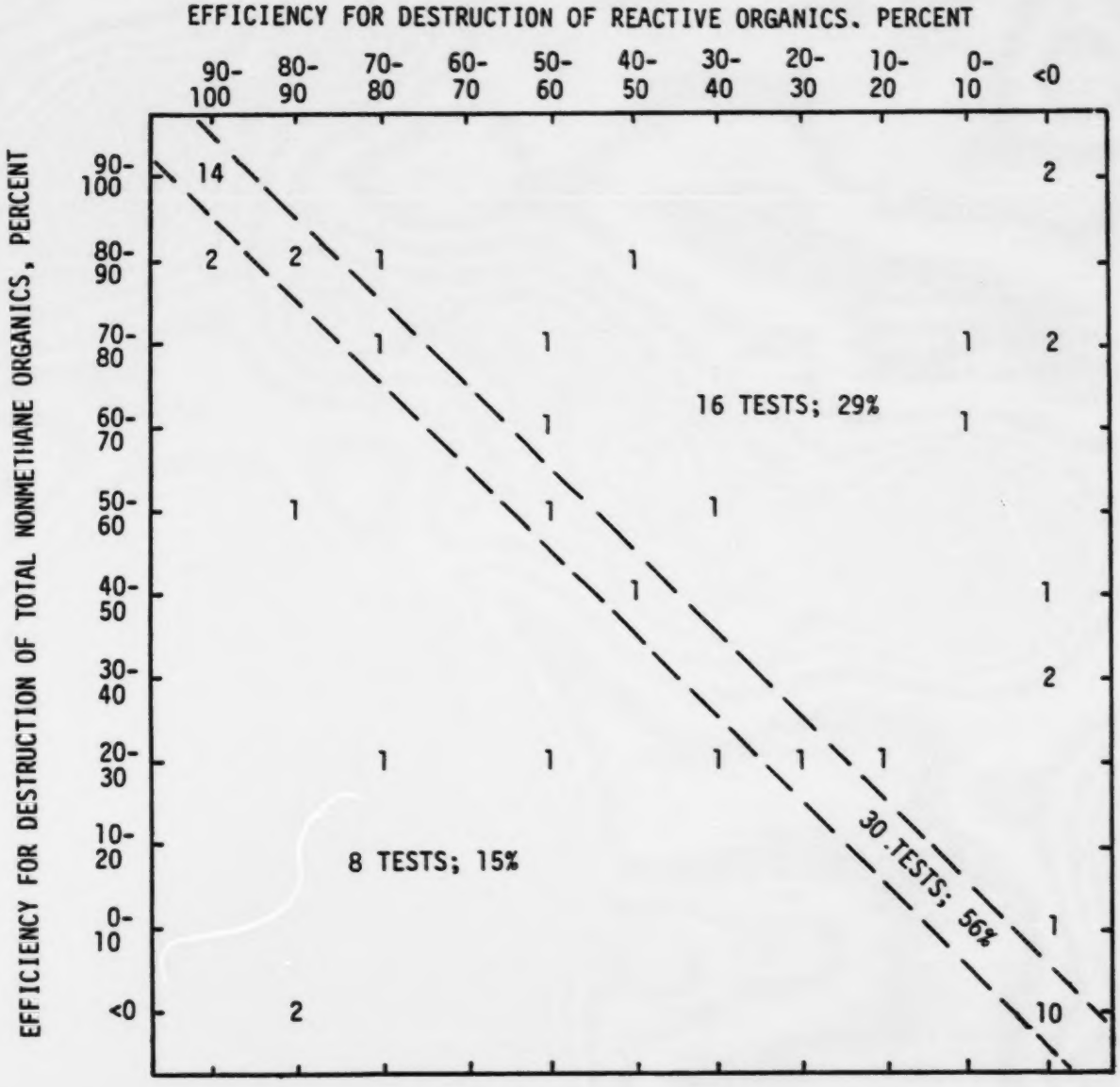



FIGURE 7. COMPARISON OF AFTERBURNER EFFICIENCIES FOR TOTAL AND REACTIVE ORGANICS

and reactive organics are considered important, it is necessary to test for each as the efficiency for controlling one type of emission may not permit estimation of control efficiency for the other type of emission.

Aldehydes

Concerning aldehydes, a pollutant that can be produced in low temperature, lean flames (such as occur in afterburners), the test reports did not contain sufficient data to calculate inlet and outlet aldehyde values on a weight basis. However, a brief comparison based on aldehyde concentrations gives results as follows:

outlet concentration < inlet concentration = 17 cases
outlet concentration > inlet concentration = 17 cases

Hence, afterburners were just as likely to increase aldehyde concentrations in a gas stream as they are to lower them. Based on inlet concentration ranges, the same analysis gives the following results:

| inlet aldehyde concentration; ppm | 0-5 | 5+ -10 | 10+ -30 | > 30 |
|---|---|---|---|---|
| outlet < inlet | 1 | 3 | 3 | 10 |
| outlet > inlet | 5 | 3 | 9 | 0 |

Not unexpectedly, these results show that afterburners are likely to increase aldehyde concentrations when inlet concentrations are low to moderate; and are likely to cause a reduction in aldehyde concentrations if inlet concentrations are high.

## IMPACT OF LESS EFFICIENT AFTERBURNERS ON HYDROCARBON EMISSIONS

The impact of afterburners being less efficient than is generally assumed for environmental assessment studies has been evaluated, both on a national and a local basis.

Considering the national viewpoint, Table 7 and Figure 2 illustrate national emissions of volatile nonmethane organics from stationary sources with an assumed afterburner efficiency of about 90 percent. Modifying these figures to consider that afterburners are applied to 50 percent of the sources for which they are considered amenable, national emissions of volatile nonmethane organics from sources utilizing afterburners is estimated to be 280,350 MT/yr. However, if afterburners are only 76 percent efficient (as shown earlier), instead of 90 percent efficiency, the outlet emission could be 596,000 MT/yr. This value is 315,650 MT/yr greater than the former value. Hence, based on the assumptions that:

1. the test data presented in Table 9 are representative of the performance of all afterburners
2. afterburners are applied to 50 percent of the sources for which they are considered amenable,

volatile nonmethane organic emissions from afterburner controlled sources are presently underestimated by 315,650 MT/yr on a nationwide basis. This value is equal to about 1.3 percent of total national volatile nonmethane organic emissions, and equal to about 2.0 percent of national man-related volatile nonmethane organic emissions. Such an error in estimating national emissions is probably not significant, as many of the values used in compiling Table 7 are not known to such accuracies.

Now, considering the impact on specific locales, it can reasonably be assumed that, for well populated areas, nearly all volatile nonmethane organic emissions are from sources amenable to controls. That is, in populated areas uncontrolled sources such as open burning and solid waste disposal to other than incinerators would be absent and natural sources would be present

in much smaller proportions than in the nation as a whole. Considering that afterburners are applied to one-half of the stationary sources in a populated area, the impact of poorer afterburners performance (76 percent versus 90 percent) would be an underestimation of volatile nonmethane organic emissions from stationary sources by up to 27 percent, depending on the distribution of types of industry. Such an error could have a significant impact on local air pollution control strategies, and in the evaluation of air pollution control efforts.

Data on afterburner performance on organic particulate were not available; hence, similar values could not be calculated for these emissions.

## RECOMMENDATIONS FOR FURTHER RESEARCH

There are two major areas in which additional afterburner research is required. These are:

1. measurements of the performance of typical "in-service" afterburners
2. studies of the relationships between afterburner performance and major design variables, especially with regards to mixing and turbulence.

The scarcity of data on typical in-service afterburners is such that meaningful analyses of the impact of afterburners of national hydrocarbon emissions is risky. The analysis reported here used the "best" available source of afterburner emissions data and showed that afterburner performance is not likely to be as good as normally expected. However, the data base was small and may be biased by the distribution of sources within the area served by this single agency. Also, basic design parameters were not recorded and, thus, parametric analyses cannot be performed. Hence, the primary need is for a well designed field measurement program to expand the available data base, both in breadth and in depth.

Secondly, various studies have been conducted to show the relationship between destruction of various chemical species and potential afterburner characteristics as measured by time/temperature profiles. However, these studies have usually defined that mixing be nearly perfect, and thus, have only studied chemical kinetics. The physical aspects of afterburner combustion, mixing and turbulence, have been largely ignored. Thus, a study relating afterburner performance to mixing and turbulence will greatly improve the design tools available to afterburner manufacturers. As discussed later, it is suggested that such a program be carried out using a mobile afterburner test unit.

## Field Program Of Emission Measurement For In-Service Afterburners

It is recommended that a field measurement program be initiated to measure the performance of at least 25 in-service afterburners. To be meaningful, the field measurement program should have the following features:

1. Include a range of afterburner sizes, types, emission sources, and designs.
2. Be conducted in such a manner as to ensure that afterburners are not adjusted, repaired, tuned up, or otherwise prepared prior to the test. This will be difficult and can only be accomplished with cooperative owners and operators.
3. Reasonably complete emission measurement at the inlet and outlet.
4. Reasonably complete recording of afterburner design features and condition (settings, maintenance, etc.).
5. Measurement of temperature and flow profiles and gas composition within the afterburner and/or across the afterburner outlet.

To be compatible with other EPA programs and goals, it is likely that Level 1 emission measurements should be included in this study.

Although it is recommended that various types of afterburners be included in this program, it is recommended that it be limited to direct flame and thermal afterburners, unless considerably more than 25 units are included (say 35). Eliminating one type of afterburner from a minimum size sample will avoid dilution of the test effort among too many variables.

## Program To Relate Afterburner Performance To Major Design Variables

The second area of needed research is in relating afterburner performance to afterburner design, especially as regards mixing and turbulence. With regards to mixing, a wide variety of afterburner designs exist--they range from units with single tangential burners to units with a grid of burner ports. Few data exist to relate afterburners effectiveness to the mixing method employed. If the field measurement program described above is conducted, some data of this type will become available. However, it will be limited to a relatively small number of afterburner designs and emission sources. Also, it may be difficult to extrapolate the field data to sources emitting different hydrocarbon species.

Therefore, it is recommended that a laboratory-scale afterburner test program be initiated to permit testing a wider variety of mixing designs and a wider variety of emission sources. As discussed below, such a test program might best be conducted using a Mobile Afterburner Test Unit.

## Limits to Laboratory Testing of Afterburners

The typical procedure for conducting experimental studies of afterburner systems is to construct a full or scaled-down incinerator in the laboratory, and to conduct a testing program using synthesized gas streams.

Laboratory testing is an excellent way to define the requirements (time, temperature, etc.) for incinerating specific hydrocarbon species. Conditions are well controlled and efficiencies and global reaction rates can be determined.

Also, laboratory testing can be a useful tool for generating design data for an afterburner, where the design engineers have real performance data on the application of similar afterburner designs to similar gas streams. In that case, the laboratory testing assists in a small extrapolation of current afterburner performance data.

Conversely, laboratory testing is not a good test procedure for evaluating the performance of incinerators in some "real life" conditions. This is especially true when considering the application of an afterburner to a stream for which little performance data exist for similar afterburners applied to similar gas streams. The major defect with laboratory testing is

that the contaminated gas stream usually is not truly representative of the real gas stream. For convenience (or simplicity), it is typical that the gas stream used for laboratory testing is much simplier than real gas streams. In fact, it is typical to conduct laboratory testing using only the single major hydrocarbon component of the gas stream of interest. Thus, the presence of other hydrocarbon species is ignored. Also, the presence of other materials (e.g., particulates, sulfur compounds, chlorine compounds, etc.) generally will be ignored--unless these materials are the major pollutants of interest.

Secondly, laboratory testing most frequently is conducted at one, or a series of, steady-state conditions. Thus, laboratory testing programs ignore operation at off-design conditions and at transcient conditions. If the source being considered for application of an afterburner operates at widely varying and transcient conditions, testing at one or a few steady-state conditions will not produce the performance data required.

Limits to Field Testing

One alternative to laboratory testing is to conduct tests on full size afterburners that are installed in operating plants. The second alternative is to conduct field testing of laboratory or pilot-scale afterburners.

Full scale testing within a limited range of variables ocassionally is done as part of emissions performance tests. An example is testing an afterburner at 1200 F, 1300 F, and 1400 F to determine the minimum operating temperature (and minimum fuel firing rate) that will enable the source to meet emission regulations. However, full scale afterburner testing over a wide range of variables (temperature, flow rates, etc.) generally is impractical. Limitations to testing full scale afterburners over a wider range of variables include:

- hardware constraints (size, shape, etc.)
- materials limitations, which limit peak temperatures
- limitations of the source for generating variable input conditions (flow rates, temperatures, gas compositions, etc.)
- fear of damage to the afterburner, followed by shutdown of the process because emission control devices are inoperable.

## Advantages of Mobile Afterburner Test Unit

It is suggested that effective afterburner testing could be conducted using laboratory or pilot scale afterburners in the field. Test afterburners could be mounted on flat-bed trucks in a manner similar to that used by EPA for other mobile emission control tests units, for example, the ESP, scrubber, and baghouse mobile units. The mobile afterburner test unit could be taken to various sites or sources and test programs could be conducted using gas streams withdrawn from the exhaust streams of real processes.

A mobile afterburner test unit would permit testing of gas streams with the same complex gas mixtures as fed to in-service afterburners. Also, transient conditions could be followed as they occur in the process, or transient conditions could be simulated by varying the rate of withdraw of test gas from the main gas stream.

Finally, using a mobile afterburner test unit would permit widely varying test conditions to be used, without fear of damaging an expensive and needed full-scale emission control system.

## REFERENCES


1. Psyhojos, T. G., "A New Field Proven System for Clean-Up of Hydrocarbon Emissions by Thermal Oxidation--From Service Station to Pipe Line Deliveries," Paper No. 77-43.5, Presented at Annual Meeting, APCA (June 20-24, 1977), Toronto.

2. Hemsath, K. H. and Thekdi, A. C., "Air Pollution Control in the Carbon Baking Process", Journal APCA, Volume 24, No. 1 (January, 1974,) PP. 60-63.

3. Hemsath, K. H., Thekdi, A. C. and Lewis, F. M., "Application of Reaction Kinetics and Mixing Studies in Design of a Fume Incinerator", Paper No. 73-299, Presented at Annual Meeting APCA, (June 24-28, 1973),Chicago.

4. Kenson, R. E., Cho, S. S., Huston, R. P., Duffee, R. A., and Hopper, T.G., "Development of Effective Incineration Processes for Toxic Organic Air Pollutants", Paper No. 77-19.2, Presented at Annual Meeting APCA, (June 20-24, 1977), Toronto

5. Schuetzle, D., and Levine, S. P., "Organic Emissions from Stationary Sources - I. Analytical Techniques for the Evaluation of Catalytic Control Devices," Paper 77-9.1, Presented at Annual Meeting APCA, (June 20-24, 1977), Toronto.

6. Miller, M. R., and Wilhoyte, H. J., "A Study of Catalysts Support Systems for Fume-Abatement of Hydrocarbon Solvents," Paper No. 67-123, Presented at Annual Meeting APCA, (1967)

7. Waid, D. E., "Effective Methods of Direct Flame Incineration of Organic Materials", Presented to Meeting East Central Section APCA, (September, 1968), Youngstown, Ohio.

8. Benforado, D. M., "Air Pollution Control by Direct Flame Incinceration in the Paint Industry," Journal Paint Technology, Vol. 39, No. 508, (May, 1967), 265-266.

9. Chapter 5-303 of the Vermont Environmental Laws as reported in the Environment Reporter, State Air Laws, pp. 34 and 35, revised (June 30, 1978).

10. Lee, K., Hansen, J. L., Macauley, D. C., "Predictive Model of the Time-Temperature Requirements for Thermal Destruction of Dilute Organic Vapors", APCA Paper No. 79-10.1, Presented at Annual Meeting APCA, (June 24-29, 1979), Cincinnati, Ohio.

11. Cavanaugh, E.C., Owen, M.L., Nelson, T.P., Carroll, J.R. and Colley, J.D., "Hydrocarbon Pollutants from Stationary Sources", EPA-600-7-77-110, U. S. Environmental Protection Agency, Washington, D.C., (1977), 318 pp.

## APPENDIX A

## LOS ANGELES HYDROCARBON VAPOR REGULATIONS

### Rule 56. Storage of Petroleum Products

A person shall not place, store or hold in any stationary tank, reservoir or other container of more than 40,000 gallons capacity any gasoline or any petroleum distillate having a vapor pressure of 1.5 pounds per square inch absolute or greater under actual storage conditions, unless such tank, reservoir or other container is a pressure tank maintaining working pressures sufficient at all times to prevent hydrocarbon vapor or gas loss to the atmosphere, or is designed and equipped with one of the following vapor loss control devices, properly installed, in good working order and in operation:

a. A floating roof, consisting of a pontoon type or double-deck type roof, resting on the surface of the liquid contents and equipped with a closure seal, or seals, to close the space between the roof edge and tank wall. The control equipment provided for ib this paragraph shall not be used if the gasoline or petroleum distillate has a vapor pressure of 11.0 pounds per square inch absolute or greater under actual storage conditions. All tank gauging and sampling devices shall be gas-tight except when gauging or sampling is taking place.

b. A vapor recovery system, consisting of a vapor gathering system capable of collecting the hydrocarbon vapors and gases discharged and a vapor disposal system capable of processing such hydrocarbon vapors and gases so as to prevent their emission to the atmosphere and with all tank gauging and sampling devices gas-tight except when gauging or sampling is taking place.

c. Other equipment of equal efficiency, provided such equipment is submitted to and approved by the Air Pollution Control Officer.

Rule 59. Oil-Effluent Water Separator

(Effective until July 1, 1972 for all equipment operating under permit as of June 29, 1971. See amended Rule on following page.)

A person shall not use any compartment of any single or multiple compartment oil-effluent water separator which compartment receives effluent water containing 200 gallons a day or more of any petroleum product or mixture of petroleum products from any equipment processing, refining, treating, storing or handling kerosine or other petroleum product of equal or greater volatility than kerosine, unless such compartment is equipped with one of the following vapor loss control devices, properly installed, in good working order and in operation:

a. A solid cover with all openings sealed and totally enclosing the liquid contents. All gauging and sampling devices shall be gas-tight except when gauging or sampling is taking place.

b. A floating roof, consisting of a pontoon type or double-deck type roof, resting on the surface of the liquid contents and equipped with a closure seal, or seals, to close the space between the roof edge and container wall. All gauging and sampling devices shall be gas-tight except when gauging or sampling is taking place.

c. A vapor recovery system, consisting of a vapor gathering system capable of collecting the hydrocarbon vapors and gases discharged and a vapor disposal system capable of processing such hydrocarbon vapors and gases so as to prevent their emission to the atmosphere and with all tank gauging and sampling devices gas-tight except when gauging or sampling is taking place.

d. Other equipment of equal efficiency, provided such equipment is submitted to and approved by the Air Pollution Control Officer.

This rule shall not apply to any oil-effluent water separator used exclusively in conjunction with the production of crude oil.

For the purpose of this rule, "kerosine" is defined as any petroleum product which, when distilled by ASTM standard test Method D 86-56, will give a temperature of 401 F, or less at the 10 percent point recovered.

Rule 59. Effluent Oil Water Separators

(Effective June 29, 1971 for any equipment not completed and put into service. Effective for all equipment after July 1, 1972.)

A person shall not use any compartment of any vessel or device operated for the recovery of oil from effluent water which recovers 200 gallons a day or more of any petroleum products from any equipment which processes, refines, stores, or handles hydrocarbons with a Reid vapor pressure of 0.5 pound or greater, unless such compartment is equipped with gauging or sampling is taking place:

a. A solid cover with all openings sealed and totally enclosing the liquid contents of that compartment.

b. A floating pontoon or double-deck type cover, equipped with closure seals to enclose any space between the cover's edge and compartment well.

c. A vapor recovery system, which reduces the emission of all hydrocarbon vapors and gases into the atmosphere by at least 90 percent by weight.

d. Other equipment of an efficiency equal to or greater than a, b, or c, if approved by the Air Pollution Control Officer.

This rule shall not apply to any oil-effluent water separator used exclusively in conjunction with the production of crude oil, if the water fraction of the oil-water effluent entering the separator contains less than 5 parts per million hydrogen sulfide, organic sulfides, or a combination thereof.

This amendment shall be effective at the date of its adoption for any equipment not then completed and put into service. As to all other equipment this amendment shall be effective on July 1, 1972.

Rule 61. Gasoline Loading into Tank Trucks and Trailers

(Effective until July 1, 1972 for all equipment operating under permit as of June 29, 1971. See amended Rule on following page.)

A person shall not load gasoline into any tank truck or trailer from any loading facility unless such loading facility is equipped with a vapor collection and disposal system or its equivalent, properly installed, in good working order and in operation.

When loading is effected through the hatches of a tank truck or trailer with a loading arm equipped with a vapor collecting adaptor, a pneumatic, hydraulic or other mechanical means shall be provided to force a vapor-tight seal between the adaptor and the hatch. A means shall be provided to prevent liquid gasoline drainage from the loading device when it is removed from the hatch of any tank truck or trailer, or to accomplish complete drainage before such removal.

When loading is effected through means other than hatches, all loading and vapor lines shall be equipped with fittings which make vapor-tight connnections and which close automatically when disconnected.

The vapor disposal portion of the system shall consist of one of the following:

a. A vapor-liquid absorber system with a minimum recovery efficiency of 90 percent by weight of all the hydrocarbon vapors and gases entering such disposal system.

b. A variable vapor space tank, compressor, and fuel gas system of sufficient capacity to receive all hydrocarbon vapors and gases displaced from the tank trucks and trailers being loaded.

c. Other equipment of at least 90 percent efficiency, provided such equipment is submitted to and approved by the Air Pollution Control Officer.

This rule shall not apply to the loading of gasoline into tank trucks and trailers from any loading facility from which not more than 20,000 gallons of gasoline are loaded in any one day.

For the purpose of this rule, any petroleum distillate having a Reid vapor pressure of 4 pounds or greater shall be included by the term "gasoline".

For the purpose of this rule, "loading facility" means any aggregation or combination of gasoline loading equipment which is both (1) possessed by one person, and (2) located so that all the gasoline loading outlets for such aggregation or combination of loading equipment can be encompassed within any circle of 300 feet in diameter.

Rule 61. Organic Liquid Loading

(Effective June 29, 1971 for any equipment not completed and put into service. Effective for all equipment after July 1, 1972.)

A person shall not load organic liquids having a vapor pressure of 1.5 psia or greater under actual loading conditions into any tank truck, trailer, or railroad tank car from any loading facility unless the loading facility is equipped with a vapor collection and disposal system or its equivalent approved by the Air Pollution Control Officer.

Loading shall be accomplished in such a manner that all displaced vapor and air will be vented only to the vapor collection system. Measures shall be taken to prevent liquid drainage from the loading device when it is not in use or to accomplish complete drainage before the loading device is disconnected.

The vapor disposal portion of the vapor collection and disposal system shall consist of one of the following:

a. An absorber system or condensation system which processes all vapors and recovers at least 90 percent by weight of the organic vapors and gases from the equipment being controlled.

b. A vapor handling system which directs all vapors to a fuel gas system.

c. Other equipment of an efficiency equal to or greater than a or b if approved by the Air Pollution Control Officer.

This rule shall apply only to the loading of organic liquids having a vapor pressure of 1.5 psia or greater under actual loading conditions at a facility from which at least 20,000 gallons of such organic liquids are loaded in any one day.

"Loading facility", for the purpose of this rule, shall mean any aggregation or combination of organic liquid loading equipment which is both (1) possessed by one person, and (2) located so that all the organic liquid loading outlets for such aggregation or combination of loading equipment can be encompassed within any circle of 300 feet in diameter.

This amendment shall be effective at the date of its adoption for any equipment not then completed and put into service. As to all other equipment this amendment shall be effective on July 1, 1972.

Rule 66. Organic Solvents

a. A person shall not discharge into the atmosphere more than 15 pounds of organic materials in any one day, nor more than 3 pounds in any one hour, from any article, machine, equipment or other contrivance, in which any organic solvent or any material containing organic solvent comes into contact with flame or is baked, heat-cured or heat-polymerized, in the presence of oxygen, unless said discharge has been reduced by at least 85 percent. Those portions of any series of articles, machines, equipment, or other contrivances designed for processing a continuous web, strip or wire which emit organic materials and using operations described in this section shall be collectively subject to compliance with this section.

b. A person shall not discharge into the atmosphere more than 40 pounds of organic materials in any one day, nor more than 8 pounds in any one hour, from any article, machine, equipment or other contrivance used under conditions other than described in section (a), for employing or applying, any photochemically reactive solvent, as defined in section (k), or material containing such photochemically reactive solvent, unless said discharge has been reduced by at least 85 percent. Emissions of organic materials into the atmosphere resulting from air or heated drying of products for the first 12 hours after their removal from any article, machine, equipment, or other contrivance described in this section shall be included in determining compliance with this section. Emissions resulting from baking, heat-curing, or heat-polymerizing as described in section (a)

shall be excluded from determination of compliance with this section. Those portions of any series of articles, machines, equipment, or other contrivances designed for processing a continuous web, strip or wire which emit organic materials and using operations described in this section shall be collectively subject to compliance with this section.

c. A person shall not, after August 31, 1974, discharge into the atmosphere more than 3000 pounds of organic materials in any one day, nor more than 450 pounds in any one hour, from any article, machine, equipment or other contrivance in which any nonphotochemically reactive organic solvent or any material containing such solvent is employed or applied, unless said discharge has been reduced by at least 85 percent. Emissions of organic materials into the atmosphere resulting from air or heated drying of products for the first 12 hours after their removal from any article, machine, equipment, or other contrivance described in this section shall be included in determining compliance with this section. Emissions resulting from baking, heat-curing, or heat-polymerizing as described in section (a) shall be excluded from determination of compliance with this section. Those portions of any series of articles, machines, equipment or other contrivances designed for processing a continuous web, strip or wire which emit organic materials and using operations described in this section shall be collectively subject to compliance with this section.

d. Emissions of organic materials to the atmosphere from the clean-up with photochemically reactive solvent, as defined in section (k), of any article, machine, equipment or other contrivance described in sections (a), (b), or (c), shall be included with the other emissions of organic materials from that article, machine, equipment or other contrivance for determining compliance with this rule.

f. Emissions of organic materials into the atmosphere required to be controlled by sections (a), (b), or (c), shall be reduced by:

1. Incineration, provided that 90 percent or more of the carbon in the organic material being incinerated is oxidized to carbon dioxide, or
2. Adsorption, or

3. Processing in a manner determined by the Air Pollution Control Officer to be not less effective than (1) or (2) above.

g. A person incinerating, adsorbing, or otherwise processing organic materials pursuant to this rule shall provide, properly install and maintain in calibration, in good working order and in operation, devices as specified in the authority to construct or the permit to operate, or as specified by the Air Pollution Control Officer, for indicating temperatures, pressures, rates of flow or other operating conditions necessary to determine the degree and effectiveness of air pollution control.

h. Any person using organic solvents or any materials containing organic solvents shall supply the Air Pollution Control Officer, upon request and in the manner and form prescribed by him, written evidence of the chemical composition, physical properties and amount consumed for each organic solvent used.

i. The provisions of this rule shall not apply to:

1. The manufacture of organic solvents, or the transport or storage of organic solvents or materials containing organic solvents.

2. The use of equipment for which other requirements are specified by Rules 56, 59, 61 or 65 or which are exempt from air pollution control requirements by said rules.

3. The spraying or other employment of insecticides, pesticides or herbicides.

4. The employment, application, evaporation or drying of saturated halogenated hydrocarbons or perchloroethylene.

5. The use of any material, in any article, machine, equipment or other contrivance described in sections (a), (b), (c) or (d), if:

(i) The volatile content of such material consists only of water and organic solvents, and

(ii) The organic solvents comprise not more than 20 percent of said volatile content, and

(iii) The volatile content is not photochemically reactive as defined in section (k).

j. For the purposes of this rule, organic solvents include diluents and thinners and are defined as organic materials which are liquids at standard conditions and which are used as dissolvers, viscosity reducers or cleaning agents, except that such materials which exhibit a boiling point higher than 220 F at 0.5 millimeter mercury absolute pressure or having an equivalent vapor pressure shall not be considered to be solvents unless exposed to temperatures exceeding 220 F.

k. For the purposes of this rule, a photochemically reactive solvent is any solvent with an aggregate of more than 20 percent of its total volume composed of the chemical compounds classified below or which exceeds any of the following individual percentage composition limitations, referred to the total volume of solvent:

1. A combination of hydrocarbons, alcohols, aldehydes, esters, ethers or ketones having an olefinic or cyclo-olefinic type of unsaturation: 5 percent
2. A combination of aromatic compounds with eight or more carbon atoms to the molecule except ethylbenzene: 8 percent
3. A combination of ethylbenzene, ketones having branched hydrocarbon structures, trichloroethylene or toluene: 20 percent.

Whenever any organic solvent or any constituent of an organic solvent may be classified from its chemical structure into more than one of the above groups of organic compounds, it shall be considered as a member of the most reactive chemical group, that is, that group having the least allowable percent of the total volume of solvents.

l. For the purposes of this rule, organic materials are defined as chemical compounds of carbon excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, metallic carbonates and ammonium carbonate.

APPENDIX B

## AFTERBURNER QUESTIONNAIRE

### GENERAL DESIGN PROCEDURES

Date: _____

Company: _____

Location: Street: _____

City: _____

State: _____ Zip Code: _____

Contact: Name: _____

Title: _____

Department/Division: _____

Telephone: ( ) _____ Extension: _____

NOTE: Please append supplemental information or details on design procedures when applicable.

Design Procedure. When approached with a request for a quotation or design of an afterburner, how are the following determined?

- Afterburner type (direct flame, thermal or catalytic)

- Size and geometry

- Choice of fuel

- Operating temperature (define operating temperature)

- Residence time (specify how residence time is defined)

- Mixing characteristics, or "How do you insure good mixing?"

- Basis for estimating pollutant removal efficiency _____

- Heat recovery (State whether heat recovery is to preheat inlet waste stream or combustion air, or to utilize waste heat outside the afterburner system.) _____

Performance Tests

- What performance tests are performed on newly installed afterburner systems? _____

- What periodic tests are conducted to insure continued afterburner performance? _____

- Who conducts performance tests?

- Can copies of test reports on any of your afterburners be otained for use in this survey?

## AFTERBURNER QUESTIONNAIRE

### PERFORMANCE DATA ON PARTICULAR AFTERBURNERS

Date: _____

Manufacturer: _____

Location: Street: _____

City: _____

State: _____ Zip Code: _____

Contact: Name: _____

Title: _____

Department/Division: _____

Telephone: (  ) _____ Extension: _____



NOTE: Please append supplemental information when applicable.

Afterburner Details

- Process application

- Pollutants removed

- Process pollutant emission rate

- Pollutant carrier gas

- Design efficiency for pollutant removal

- Size and geometry (include drawing or sketch)

- Materials of construction

- Fuel

- Flow rates:

| | Minimum | Average | Maximum |
|---|---|---|---|
| Fuel | | | |
| Combustion air | | | |
| Pollutants (for each pollutant | | | |
| | | | |
| | | | |
| | | | |

- Percent oxygen in afterburner outlet stream

- Temperature, average operating (describe measurement locations)

  Waste stream inlet

  Exhaust gas outlet

- Inlet pressure of waste stream

- Residence time (define residence time)

- Provisions for heat recovery

- Stack details

  Height _____

  Diameter _____

  Others _____

  _____

  _____

- Costs

  Capital _____

  Installation _____

  Testing _____

  Operation _____

- Operating time (e.g. hr/year) _____

  _____

- Other pertinent information _____

  _____

  _____

  _____

Design Basis. How were the following determined?

- Size and geometry _____

  _____

  _____

- Operating temperature _____

  _____

- Residence time

- Mixing characteristics

- Estimated pollutant removal efficiency

Performance Data

- Gas Analyses (copies of manufacturer's data summaries may be substituted for this entry)

| | Input | Output |
|---|---|---|
| **Inorganics** | | |
| $H_2O$ | | |
| CO | | |
| $CO_2$ | | |
| $O_2$ | | |
| $N_2$ | | |
| Halogens | | |
| **Organics** | | |
| $CH_4$ | | |
| $C_2$-$C_9$ saturated hydrocarbons | | |
| $C_{10}$ + saturated hydrocarbons | | |
| Olefins | | |
| Carbonyls as $CH_2O$ | | |
| Organic acids as HAc | | |
| Benzene | | |
| Phenol | | |
| Aromatics excluding benzene | | |
| Polynuclear organic materials (POM) | | |
| Total Organics | | |
| Total Reactive Organics* | | |
| **Particulates** | | |
| | | |
| | | |

* Defined as all olefins, substituted aromatics and aldehydes.

- Calculated vs actual performance efficiency

| Pollutant | Pollutant Removal Efficiency, % | |
|---|---|---|
| | Calculated | Measured |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

- How often are tests made to assure continued proper performance? Who performs tests (user, manufacturer, EPA, etc.)?

# APPENDIX C

## RESPONSES TO AFTERBURNER QUESTIONNAIRE BY FOUR MANUFACTURERS

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

## CONTENTS

Page

RESPONSE FROM MANUFACTURER I . . . . . C-1

RESPONSE FROM MANUFACTURER II . . . . . C-12

RESPONSE FROM MANUFACTURER III . . . . . C-23

RESPONSE FROM MANUFACTURER IV . . . . . C-34

9-1/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS



PAGE NUMBER
EPA-287 (Cin.)
(4-76)

RESPONSE FROM MANUFACTURER I

AFTERBURNER QUESTIONNAIRE

GENERAL DESIGN PROCEDURES

Date: _____

Company: _____

Location: Street: _____

City: _____

State: _____ Zip Code: _____

Contact: Name: _____

Title: _____

Department/Division: _____

Telephone: ( ) _____ Extension: _____

NOTE: Please append supplemental information or details on design procedures when applicable.

Design Procedure. When approached with a request for a quotation or design of an afterburner, how are the following determined?

- Afterburner type (direct flame, thermal or catalytic) — Direct flame is the standard product.

- Size and geometry — Based on design flow rates specified by the customer, plus available space.

- Choice of fuel — Customer Spec. Capabilities of natural gas, propane, # 2 - #6 oil.

- Operating temperature (define operating temperature) — Operating temperature is the incineration temperature. 1500° F is the maximum standard level. Customer specifications handled on an individual basis.

- Residence time (specify how residence time is defined) — Residence time is the interval of time at which the process stream is at the incineration temperature. 0.3 to 0.5 seconds is standard, unless customer specifies a distinct period.

- Mixing characteristics, or "How do you insure good mixing?" — Raw gas burner used for natural gas firing. A slotted cylinder is used for oil firing applications.

- Basis for estimating pollutant removal efficiency

  Field test data, available industry publications, Lab data on pilot units:

- Heat recovery (State whether heat recovery is to preheat inlet waste stream or combustion air, or to utilize waste heat outside the afterburner system.)

  Primary air to gas heat recovery to preheat the process stream. Secondary air to gas to heat the burning combustion air or for plant heating. Waste heat boilers and economizers also available.

Performance Tests

- What performance tests are performed on newly installed afterburner systems?

  Hydrocarbon efficiency, flow and temperature profiles, fuel comsumption, heat recovery performance, system pressure dip data, fan performance, particulate loadings.

- What periodic tests are conducted to insure continued afterburner performance?

  Hydrocarbon destruction chamber temperature profiles.

- Who conducts performance tests?

  Primarily done by third party. Test firms retained by the customer.

- Can copies of test reports on any of your afterburners be otained for use in this survey?

  Prior combined approval of ultimate customer will be required.

## AFTERBURNER QUESTIONNAIRE

### PERFORMANCE DATA ON PARTICULAR AFTERBURNERS

Date: _____

Manufacturer: _____

Location: Street: _____

City: _____

State: _____ Zip Code: _____

Contact: Name: _____

Title: _____

Department/Division: _____

Telephone: (  ) _____ Extension: _____

NOTE: Please append supplemental information when applicable.

Afterburner Details

- Process application: Metal Litho sheet coating oven
- Pollutants removed: Toluene
- Process pollutant emission rate: 214.8 #/hr
- Pollutant carrier gas: Ambient air heated to oven exhaust temperature (6000 Scfm)
- Design efficiency for pollutant removal: 90%
- Size and geometry (include drawing or sketch)
- Materials of construction: - External Casing - Carbon Steel
  - Heat Exchanger tubes - 316, 304SS
  - 2200° F internal insulation
- Fuel: Actual Gas

- Flow rates:

| | Minimum | Average | Maximum |
|---|---|---|---|
| Fuel | 0.95 x $10^6$ Btu/hr | | 345 x $10^6$ Btu/hr |
| Combustion air | (Raw Gas Burner - No additional air required) | | |
| Pollutants (for each pollutant | 10 GPH | | 30 GPH |
| | | | |
| | | | |
| | | | |

- Percent oxygen in after-burner outlet stream: Not available

- Temperature, average operating (describe measurement locations): 1400° F as measured by a thermocouple at the exit of the combustion chamber
  - Waste stream inlet: 300° F
  - Exhaust gas outlet: 998° F

- Inlet pressure of waste stream: Approximately 8" W.C.

- Residence time (define residence time): 0.3 seconds, based on the minimum path length along the combustion chamber

- Provisions for heat recovery: Primary air to gas tubular heat exchanger to preheat the process stream prior to entry to the combustion chamber.

- Stack details

  Height: Standard is 10' - 0" rain protected stock

  Diameter: 31" ID, uninsulated

  Others:

- Costs

  Capital: $80,000 equipment only

  Installation: $175,000 total installed cost

  Testing:

  Operation:

- Operating time (e.g. hr/year) 6480

- Other pertinent information

Design Basis. How were the following determined?

- Size and geometry: Size based on flow rates; Geometry based on available customer space.

- Operating temperature: 1400° F standard design for toluene.

- Residence time: 0.3 seconds adequate to combust toluene.
- Mixing characteristics: Maxon raw gas burner used to achieve mixing of the process stream and flame.
- Estimated pollutant removal efficiency: 90%

Performance Data

- Gas Analyses (copies of manufacturer's data summaries may be substituted for this entry)

| | Input | Output |
|---|---|---|
| **Inorganics** | | |
| $H_2O$ | NM | NM |
| CO | NM | |
| $CO_2$ | NM | |
| $O_2$ | 6210 | |
| $N_2$ | 20,800 | |
| Halogens | | |
| **Organics** | | |
| $CH_4$ | | |
| $C_2$-$C_9$ saturated hydrocarbons | | |
| $C_{10}$ + saturated hydrocarbons | | |
| Olefins | | |
| Carbonyls as $CH_2O$ | | |
| Organic acids as HAc | | |
| Benzene | | |
| Phenol | | |
| Aromatics excluding benzene | | |
| Polynuclear organic materials (POM) | | |
| Total Organics | | |
| Total Reactive Organics* | 214.8 #/hr | traces |
| **Particulates** | | |
| | None | None |
| | | |

Sampled for organic compounds only

* Defined as all olefins, substituted aromatics and aldehydes.

- Calculated vs actual performance efficiency

| Pollutant | Pollutant Removal Efficiency, %<br>Calculated | Measured |
|---|---|---|
| Toluene | 90% | 99% |
| | | |
| | | |
| | | |
| | | |
| | | |

- How often are tests made to assure continued proper performance? Who performs tests (user, manufacturer, EPA, etc.)?

Unknown

RESPONSE FROM MANUFACTURER II

AFTERBURNER QUESTIONNAIRE

GENERAL DESIGN PROCEDURES

Date: January 29, 1979

NOTE: Please append supplemental information or details on design procedures when applicable.

Design Procedure. When approached with a request for a quotation or design of an afterburner, how are the following determined?

- Afterburner type (direct flame, thermal or catalytic)

  Technical feasibility within explosive limits. Catalyst temp. limits & economic evaluation of alternatives.

- Size and geometry

  Application of Design standards to determine best fit and power requirements (pressure drop) space considerations.

- Choice of fuel

  1. Economics, 2. Availability, 3. Performance preference: a) Elect, b) Natural gas, c) $No_2$ fuel oil.

- Operating temperature (define operating temperature)

  Operating temperature is the temperature which will sustain a reaction at a desired performance level.

- Residence time (specify how residence time is defined)

  Residence time is volume of process/unit time per volume of work area where the operating temperature is sustained.

- Mixing characteristics, or "How do you insure good mixing?"

  Mixing is accomplished by geometric considerations affecting velocity, flow distribution, and turbulance utilizing, orifice chocking, baffles and turning vanes & transitions.

- Basis for estimating pollutant removal efficiency

  Laboratory testing.

- Heat recovery (State whether heat recovery is to preheat inlet waste stream or combustion air, or to utilize waste heat outside the afterburner system.)

  Heat recovery is predominantly to preheat the inlet waste stream and second preheating air to customers ovens of other process equipment.

Performance Tests

- What performance tests are performed on newly installed afterburner systems?

  Electrical Systems & Burner performance checkout. The customers process is after unavailable, fan performance is checked and balanced; customers conduct compliance test when required.

- What periodic tests are conducted to insure continued afterburner performance?

  Contract maintenance is recommended; however, periodic testing is usually at the discretion of the purchaser.

- Who conducts performance tests?

The Service Department conducts checkouts. Customers generally retain outside source testing firm; however, test and development has test equipment available to perform testing at customers request on a contract basis.

- Can copies of test reports on any of your afterburners be otained for use in this survey?

We have tested only a few units; never rigorously.

AFTERBURNER QUESTIONNAIRE

PERFORMANCE DATA ON PARTICULAR AFTERBURNERS

Date: January 29, 1979

NOTE: Please append supplemental information when applicable.

Afterburner Details

- Process application: Catalytic Incinerator. Spreader. Adhesive.
- Pollutants removed: Toluene; Methyl Ethyl Ketone; Methane
- Process pollutant emission rate: 4 lbs/min; MEK; Toluene
- Pollutant carrier gas: air 7760 cfm @70°F
- Design efficiency for pollutant removal: 90%
- Size and geometry (include drawing or sketch): Dwg D-25420-A
- Materials of construction: structural shell frame & casing with cast refractory inner lining.
- Fuel: Natural gas.

- Flow rates:

| | Minimum | Average | Maximum |
|---|---|---|---|
| Fuel | | 4200 scfm | natural gas |
| Combustion air | | none | (uses process) |
| Pollutants (for each pollutant | | 4#/min | total |
| | | | |
| | | | |
| | | | |

- Percent oxygen in after-burner outlet stream: 21% approximately

- Temperature, average operating (describe measurement locations): 650°F at inlet
  70 catalyst bed
  - Waste stream inlet: 70°F
  - Exhaust gas outlet: 499°F

- Inlet pressure of waste stream: -2.0" $H_2O$ gauge

- Residence time (define residence time): 60,000 per hour
  contact time of catalyst

- Provisions for heat recovery: Tubular heat exchange tube side 70°F
  in 421°F out Shell side 850° in 495°F
  out efficiency 45%

- Stack details

  Height

  Diameter

  Others

- Costs

  Capital $78,300 (1977)

  Installation

  Testing 6900

  Operation

- Operating time (e.g. hr/year) 6000 hrs/year

- Other pertinent information

Design Basis. How were the following determined?

- Size and geometry application of design stds. influenced by burner size, catalyst volume, fan size, heat exchanger design, and pressure drop

- Operating temperature 850°F leaving catalyst

- Residence time — 60,000 per hour SV

- Mixing characteristics — Pressure drop across catalyst insures proper mixing catalyst is layered to assure mixing between the layers.

- Estimated pollutant removal efficiency — 90%

Performance Data

- Gas Analyses (copies of manufacturer's data summaries may be substituted for this entry)

| | Input | Output |
|---|---|---|
| **Inorganics** | | |
| $H_2O$ | The customer ran | confidential |
| CO | tests. We are not | at liberty to |
| $CO_2$ | divulge their result. | |
| $O_2$ | | |
| $N_2$ | | |
| Halogens | | |
| **Organics** | | |
| $CH_4$ | | |
| $C_2$-$C_9$ saturated hydrocarbons | | |
| $C_{10}$ + saturated hydrocarbons | | |
| Olefins | | |
| Carbonyls as $CH_2O$ | | |
| Organic acids as HAc | | |
| Benzene | | |
| Phenol | | |
| Aromatics excluding benzene | | |
| Polynuclear organic materials (POM) | | |
| Total Organics | | |
| Total Reactive Organics* | | |
| **Particulates** | | |
| | | |

* Defined as all olefins, substituted aromatics and aldehydes

- Calculated vs actual performance efficiency

| Pollutant | Pollutant Removal Efficiency, % | |
|---|---|---|
| | Calculated | Measured |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

- How often are tests made to assure continued proper performance? Who performs tests (user, manufacturer, EPA, etc.)?

User checks performance 2 times per year. Efficiency approximately 97 - 98%.

RESPONSE FROM MANUFACTURER III

AFTERBURNER QUESTIONNAIRE

GENERAL DESIGN PROCEDURES

Date: January 30, 1979

NOTE: Please append supplemental information or details on design procedures when applicable.

Design Procedure. When approached with a request for a quotation or design of an afterburner, how are the following determined?

- Afterburner type (direct flame, thermal or catalytic) — Determine by heat content of gas impurities in the gas, and required % conversion of pollutants. has been specializing in catalytic. Our subsequent comments are limited to catalytic units.
- Size and geometry — Catalyst bed determines size based on space velocity. Heat exchangers size depends on waste heat available and percent economically recoverable. Preheat & mixing add to length geometry changes slightly with location.
- Choice of fuel — Natural gas, or propane preferred. Clean oil (no sulfur) is alternate.
- Operating temperature (define operating temperature) — Operating temperature is determined for each case which usually has a combination of gases. It varies with space velocity and the level of abatement to be achieved. Inlet temperature must also be maintained at a minimum.
- Residence time (specify how residence time is defined) — For catalytic units, residence time is stated as space velocity which is SCFH of gas per $ft^3$ of catalyst. Proprietary kinetic equations along with mass transfer considerations are used ~~to determine an overall reaction rate. This reaction rate is then used in other proprietary formulas to determine space~~ velocit for the particular catalyst being used.
- Mixing characteristics, or "How do you insure good mixing?" — Mixing is achieved following the preheater by baffling which insures thorough mixing before entering the catalyst bed.

- Basis for estimating pollutant removal efficiency

  Data from our Research Lab, previous experience, or run a test.

- Heat recovery (State whether heat recovery is to preheat inlet waste stream or combustion air, or to utilize waste heat outside the afterburner system.)

  The waste heat is used to preheat the waste stream and/or the combustion air usually a max of 45 to 50% is achieved unless less is needed. Waste heat boilers are left to the customer. The economics of heat recovery depend on the type and cost of fuel that is available.

Performance Tests

- What performance tests are performed on newly installed afterburner systems?

  Complete electrical test. Preheater test. Heat exchanger efficiency. Chemical conversion efficiency over the range of exhaust impurities and flowrates available. Data result in plots of space velocity vs % conversion at various operating temperatures.

- What periodic tests are conducted to insure continued afterburner performance?

  Conversion efficiency at various flow rates and temperatures. These data are compared to the plots developed during the initial tests described above. Systems are designed so that operating temperature can be increased slightly to extend the operating life of the catalyst.

- Who conducts performance tests?

Customer, , or a 3rd party, depending on what the customer desires. always can supply engineering back-up and field supervision when requested by customer.

- Can copies of test reports on any of your afterburners be otained for use in this survey?

No, this information is proprietary.

# AFTERBURNER QUESTIONNAIRE

## PERFORMANCE DATA ON PARTICULAR AFTERBURNERS

Date: January 30, 1979

NOTE: Please append supplemental information when applicable.

Afterburner Details

- Process application: Formaldehyde plant off-gas. Metal oxide process.
- Pollutants removed: Methanol, dimethyl either, carbon monoxide and formaldehyde.
- Process pollutant emission rate: 5000 SCFM off-gas per 100 million lbs per year formaldehyde.
- Pollutant carrier gas: Plant off-gas approx. 6% $O_2$, 94% $N_2$ and some $CO_2$.
- Design efficiency for pollutant removal: 99.5% or better as may be required.
- Size and geometry (include drawing or sketch): Attached drawing B-18882 is typical for 100 MM ton/year plant.
- Materials of construction: 300 series SS above 800°F. Mild steel elsewhere.
- Fuel: Natural gas and propane, dual gas train.

Fuel required only for start-up. During operation, the heat recovery exchanger allows self sustained operation because of low catalyst operating temperature.

- Flow rates:

| | Minimum | Average | Maximum |
|---|---|---|---|
| Fuel | 0 | 0 | 2225 $Ft^3/Hr$* |
| Combustion air | 0 | 0 | 500 SCFM |
| Pollutants (for each pollutant) CO | 0.6% by vol. | 0.75% by vol. | 1.28% by vol. |
| MeOH | 0.01% " | 0.04 " | 0.06 " |
| Dimethyl Ether | 0.275" | 0.375 " | 0.44 " |
| Formaldehyde | 0.0025" | 0.01 " | 0.015 " |

*Fuel required only at start-up.

- Percent oxygen in after-burner outlet stream: 6% by vol.

- Temperature, average operating (describe measurement locations): 950°F
  Outlet of catalyst
  Waste stream inlet: 70°F
  Exhaust gas outlet: 625°F

- Inlet pressure of waste stream: 12" w.c.

- Residence time (define residence time): Not answered, information proprietary.

- Provisions for heat recovery: Heat Exchanger
  40% recovery.

- Stack details

  Height — Stack was furnished by others.

  Diameter

  Others

- Costs

  Capital — Approx. $100,000

  Installation — Usually done by others.

  Testing — Approx. $3,000 at start-up no

  Operation — fuel cost. Uses existing plant blower. 500 watts electric power for instruments. Minimum attention by plant operators.

- Operating time (e.g. hr/year) — 24 Hrs/Day

  Except for usual shutdown of formaldehyde plant.

- Other pertinent information — Expected catalyst life is 3 to 5 years. Catalyst replacement cost is approximately $15,000.

Design Basis. How were the following determined?

- Size and geometry — Catalyst bed sized by proprietary formulas to give required chemical conversion. Heat exchangers sized to give self-sustained operation Burner sized to give required start-up temperatur of 400°F. Exact configuration designed to meet customers' available space & preferred location, such as roof-top, etc.

- Operating temperature — Start-up: 400°F

  Operating: 950°F outlet from catalyst bed.

- Residence time — Exact information is proprietary, but is based on space velocity. Space velocity is related to overall reaction rates determined by kinetic equations and mass transfer consideration
- Mixing characteristics — Mixing is not a problem on this particular unit since no fuel or air is added during operation. In cases where mixing is critical, baffles or other static mixers are used.
- Estimated pollutant removal efficiency — Better than 99.5% in this case. When higher or lower efficiency is required, catalyst space velocity or operating temperature can be changed to produce the most economical and fuel-efficient system.

Performance Data

Gas Analyses (copies of manufacturer's data summaries may be substituted for this entry)

| | Input | Output |
|---|---|---|
| **Inorganics** | | |
| $H_2O$ | Saturated at 70° | Essentially unchanged |
| CO vol % | .95 | .0021 |
| $CO_2$ | low | low |
| $O_2$ vol % | 6-7 | 5-6 |
| $N_2$ | Remainder | Remainder |
| Halogens | Nil | Nil |
| **Organics** | | |
| $CH_4$ | | |
| $C_2$-$C_9$ saturated hydrocarbons | | |
| $C_{10}$ + saturated hydrocarbons | | |
| Olefins | | |
| Carbonyls as $CH_2O$, vol % | 0.0034 | 0005 |
| Organic acids as HAc | | |
| Dimethyl ether, vol % | 0.375 | 0.001 |
| Methanol, vol % | 0.04 | .0005 |
| Aromatics excluding benzene | | |
| Polynuclear organic materials (POM) | | |
| Total Organics, vol % | 0.334 | 0.003 |
| Total Reactive Organics* | | |
| **Particulates** | | |
| | None | None |

* Defined as all olefins, substituted aromatics and aldehydes.

- Calculated vs actual performance efficiency

| Pollutant | Pollutant Removal Efficiency, % | |
|---|---|---|
| | Calculated (Design) | Measured (Actual) |
| CO | 98.95 | 99.78 |
| $CH_2O$ | 99.9 | Too low to measure |
| Dimethyl ether | 98.6 | 99.73 |
| MeOH | 99.9 | Too low to measure |
| | | |
| | | |

- How often are tests made to assure continued proper performance? Who performs tests (user, manufacturer, EPA, etc.)?

Weekly testing by plant personnel or as may be required to meet local EPA requirements.

RESPONSE FROM MANUFACTURER IV

AFTERBURNER QUESTIONNAIRE

GENERAL DESIGN PROCEDURES

Date: _____

Company: _____

Location: Street: _____

City: _____

State: _____ Zip Code: _____

Contact: Name: _____

Title: _____

Department/Division: _____

Telephone: ( ) _____ Extension: _____

NOTE: Please append supplemental information or details on design procedures when applicable.

Questionaire I Pg. 2 Design Procedure.

When we're approached with a request we first ask ourselves "is a combustion unit/system the correct application? There is no point quoting any unit/system when there is a potentially better and/or less expensive approach and gods knows our industry has enough history of less than the best applications.

Afterburner type

This is pretty much dictated by the process specification. If its high energy or concentration its a flare/direct burner combustion. If its low concentration you always look at catalytic first, for the obvious economy of operation. Potential catalyst contaminates may of course dictate the thermal/flame approach.

You also, of course, must look at potential secondary problems.

The classic example is burning chlorinated hydrocarbons and making hydrochloric acid, so it may have to be a dual or composite approach of an incinerator followed by a scrubber or particulate collector ie mechanical, wet, fabric or electrostatic or combination of these for particulate non combustibles or gaseous emission control.

Additionally, it may be a combination flare/direct burner combination thermal/flame application. An example is the rich fumes from a continuous pulp digestor used as fuel in the burner of a

thermal/flame unit which also handles the dilute fumes from the evaporator/seal well vent/dryer, etc. You might also follow that with an SOx absorber.

Size and Geometry.

Again, dictated by the requirement, operating enviroment, shipping clearances, fuel availability, utilities cost, operating schedule, cost of money, etc. etc. etc., in short everything conceivable.

Choice of Fuel.

Usually based upon availability, cost, consumption, composition, impurities etc. You of course prefer gas and I don't know anyone quoting coal. Oil of course is a mixed bag. You prefer distillate obviously but when its not available you look at and consider what is. A good rule is of course if its a problem for a boiler it will be worse for us, due to lack of maintenance on our non-productive equipment.

Operating Temperature.

Whatever is necessary to achieve your guaranteed performance. We usually refer to this as the highest temperature achieved in any system under normal operating conditions and load.

Residence Time

Again, whatever is necessary to achieve your required/guaranteed performance. You may also trade residence time for operating temperature depending upon economics, but generally in a thermal/flame unit 100°F may be worth half the time. This is usually not true catalytically where your reaction rate kinetics generally become asymtotic at some optimum temperature where for example they become limited by things like diffusion.

Residence time is generally defined by the time the reactants are in the reaction chamber at their average (inlet/outlet) temperature.

Mixing Characteristics

You include mechanical devices that have been proven to produce

uniform mixing. It might be a target or an orifice, or both, to break a velocity head. It could be a checker work, or a mechanical rotating device, or velocities resulting in turbulent flow, etc. etc.

Basis for estimating removal efficiency.

Estimate hell, you've got to guarantee it today.

We have a unit/system in our laboratory thats as close as we can get to adiabatic/isothermal, where we test to determine reaction rate kinetics both catalytically and thermally for individual or mixed pollutants.

We also have computer programs that utilize and integrate this data to determine the operating conditions and requirements for guaranteed performance, and thats before we even bid the job.

Heat Recovery

Which ever way or combinations that are best economically justified. Most often you'll find the first consideration is to preheat the inlet wastestream because you only need it when its available. The same is usually true for preheating combustion air if an only when its required.

Next you look for generating or near-by process energy recovery, rather than facility, because of utilization factors. In other words, best economic utilization.

Performance Tests.

Only those purchased by the customers. On combustibles it could be total combustible carbon. ie no credit for partial oxidation to CO, acids, aldehydes, etc. Or, it could be hydrogen flame ionization, where acceptable.

On NOx its usually the published Federal EPA method.

Periodic tests are usually conducted by either the enforcement agency or an outside independent and certified laboratory.

We have sold many performance certification tests and reports on our equipment.

Unfortunately all of these tests were paid for and are the property of our customers, so we are not able to offer them without their consent. Our best ones are on NOx from flare/direct burner jobs. If one of these are of interest, please advise and I'll try to get permission to make one available.

## AFTERBURNER QUESTIONNAIRE

### PERFORMANCE DATA ON PARTICULAR AFTERBURNERS

Date: _____

Manufacturer: _____

Location: Street: _____

City: _____

State: _____ Zip Code: _____

Contact: Name: _____

Title: _____

Department/Division: _____

Telephone: ( ) _____ Extension: _____

NOTE: Please append supplemental information when applicable.

Afterburner Details

- Process application: Metal Nitration
- Pollutants removed: NOx & HNO3
- Process pollutant emission rate: 190 lb/hr. Max Design
- Pollutant carrier gas: Air & Water Vapor
- Design efficiency for pollutant removal: 95%
- Size and geometry (include drawing or sketch): Drawing attached
- Materials of construction: Steel & Refractory
- Fuel: Gas, Methane or Propane
  Oil option Available

- Flow rates: SCFH

| | Minimum | Average | Maximum |
|---|---|---|---|
| Fuel CH4 | 1800 | 1890 | 1980 |
| Combustion air | 3229 | 3256 | 3646 |
| Pollutants (for each pollutant | | | |
| Nox | 1231 | 1249 | 1434 |
| HNO3 | 17 | 22 | 30 |
| | | | |

- Percent oxygen in afterburner outlet stream: 14.5% Dry

- Temperature, average operating (describe measurement locations): 2250°F Primary Reaction Zone
  - Waste stream inlet: 100-120°F
  - Exhaust gas outlet: 875-900°F (165-225% Excess Secondary Air)

- Inlet pressure of waste stream: 14.7 psia

- Residence time (define residence time): 6 sec. Primary Zone At Temperature

- Provisions for heat recovery: None

- Stack details

  Height: 46 Ft.

  Diameter: 17 1/2 In.

  Others:

- Costs (75')

  Capital: $30,000

  Installation: N/A

  Testing: $6,000

  Operation: $4.75 /hr.

- Operating time (e.g. hr/year): 6000

- Other pertinent information:

Design Basis. How were the following determined?

- Size and geometry: Development & Successful Installation Data

- Operating temperature: As necessary to consume Oxygen

- Residence time — See Pg. 3
- Mixing characteristics — Special Burner Design
- ~~Excessive~~ pollutant removal efficiency — As Measured By EPA Test Method (PDSA) 98-99%

Performance Data

- Gas Analyses (copies of manufacturer's data summaries may be substituted for this entry)

| | Input | Output |
|---|---|---|
| **Inorganics** | | |
| $H_2O$ | See Sheet #3 | |
| CO | | |
| $CO_2$ | | |
| $O_2$ | | |
| $N_2$ | | |
| Halogens | | |
| **Organics** | | |
| $CH_4$ | None | None |
| $C_2$-$C_9$ saturated hydrocarbons | | |
| $C_{10}$ + saturated hydrocarbons | | |
| Olefins | | |
| Carbonyls as $CH_2O$ | | |
| Organic acids as HAc | | |
| Benzene | | |
| Phenol | | |
| Aromatics excluding benzene | | |
| Polynuclear organic materials (POM) | | |
| Total Organics | | |
| Total Reactive Organics* | | |
| **Particulates** | | |

- Calculated vs actual performance efficiency

| Pollutant | Pollutant Removal Efficiency, %<br>Calculated | <br>Measured |
|---|---|---|
| NOx + HNO3 | 95 | 98-99 |
| | | |
| | | |
| | | |
| | | |
| | | |

- How often are tests made to assure continued proper performance? Who performs tests (user, manufacturer, EPA, etc.)?

N/A

MF'G. Supplied Performance Certification Test And Report.